Electric vehicle charging combined with load management in commercial buildings

Viivi Lemström

School of Electrical Engineering

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Thesis supervisor:

Ph.D. John Millar

Thesis advisor:

M.Sc. Tuomas Mattila

Aalto University
School of Electrical
Engineering

AALTO UNIVERSITY
SCHOOL OF ELECTRICAL ENGINEERING

ABSTRACT OF THE
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Supervisor: Ph.D. John Millar

Advisor: M.Sc. Tuomas Mattila

This research studies electric vehicle (EV) charging integrated to commercial buildings. It compares smart EV charging in smart buildings with stand-alone EV charging in buildings without a building management system. In this research, two different commercial buildings with EV charging are studied.

The intention of this research is to study what kind of technical and economic benefits are possible to achieve with a smart system, which consists of both smart charging and smart buildings, compared to a stand-alone system. To achieve this, both EV charging data and electricity consumption data for both buildings are studied heuristically by using Excel spreadsheet as a tool. The aim is to find out a way to organize the charging in the most optimized way within the constraints set by the building and by the EV charging system in each case.

As result, smart charging integrated to a smart building management system can save up to 4 500 € yearly in buildings electricity costs compared to a stand-alone system. Although the investment cost for the smart system is more expensive, during the chargers expected lifetime, the smart system becomes more profitable due to the savings in the electricity usage. The benefits achieved with the smart system are strongly connected with the size of the commercial building's EV charging system. Especially with large EV charging systems, smart charging proves to be a more viable and profitable option.

Keywords: EV charging, Building management system, Smart building, Smart charging, Smart system, Stand-alone charging, Stand-alone system, Load management, General tariff, Spot price

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Tämä työ tutkii sähköautojen latausta liitettynä kaupallisiin rakennuksiin. Työssä verrataan älykästä latausta älykkäissä rakennuksissa itsenäiseen lataukseen, joka on liitettynä rakennuksiin ilman kuormanhallintaa. Työssä tutkitaan kahta eri kaupallista rakennusta ja niissä olevaa sähköautojen latausta.

Työn tarkoitus on selvittää minkälaisia teknisiä ja rahallisia hyötyjä on mahdollista saavuttaa älykkäällä järjestelmällä, joka koostuu älykkäästä latauksesta ja älykkäästä kiinteistöstä itsenäiseen järjestelmään verrattuna. Tämän saavuttaakseen, sekä sähköauton latausta, että rakennusten sähkönkulutusta analysoidaan heuristisella menetelmällä Excel taulukkolaskentaohjelman avulla. Tavoitteena on järjestää sähköautojen lataus mahdollisimman optimaalisesti rakennusten sekä sähköautojen latauksen asettamien rajojen puitteissa kussakin tapauksessa.

Tuloksena, älykkäällä latauksella, joka on liitettynä älykkääseen rakennusautomaatiojärjestelmään, voi säästää jopa 4 500 € vuosittain sähkönkulutuksessa itsenäiseen järjestelmään verrattuna. Vaikka älykkään järjestelmän investointikustannukset ovat hintavammat, älykäs järjestelmä tulee kannattavammaksi latauslaitteiden odotetun elinkaaren aikana pienemmän sähkönkulutuksen myötä. Saavutetut hyödyt älykkäällä järjestelmällä korreloivat vahvasti kaupallisen rakennuksen latausjärjestelmän koon kanssa. Etenkin suurissa sähköautojen latausjärjestelmissä, älykäs lataus osoittautuu kannattavammaksi ja edullisemmaksi vaihtoehdoksi.

Avainsanat: Sähköautojen lataus, Rakennusautomaatiojärjestelmä, Älykäs rakennus, Älykäs lataus, Älykäs järjestelmä, Itsenäinen lataus, Itsenäinen järjestelmä, Kuormanhallinta, Yleistariffi, Spot-hinta

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Detta arbete undersöker elbilsladdning integrerat till kommersiella byggnader. Arbetet jämför smart laddning i smarta byggnader med fristående laddning i byggnader utan belastningsstyrning. I arbetet studeras två olika kommersiella byggnader med elbilsladdning.

Arbetets syfte är att undersöka de tekniska och ekonomiska fördelar som är möjliga att uppnå med ett intelligent system, som består av både smart laddning och smart byggnad, jämfört med ett fristående system. För att uppnå detta, både elbilsladdning och strömförbrukning i byggnader analyseras heuristiskt med hjälp av Excel. Målet är att hitta ett sätt att optimera laddningen inom de begränsningar som fastställts av byggnaden och elbilsladdningen i båda fallen.

Som resultat, med smart laddning som är integrerat till ett smart byggnadsautomationssystem, kan man spara upp till 4 500 € per år i elförbrukningen jämfört med ett fristående system. Även om installationskostanderna för det smarta systemet är högre, de uppnådda besparingar i elförbrukningen under laddarnas förväntad livslängd gör det smarta systemet mer lönsamt. De uppnådda fördelarna med det smart systemet korrelerar starkt med storleken på den kommersiella byggnadens laddningssystem. Speciellt inom stora laddningssystem, smarta laddningen visar sig att vara mer fördelaktigt och förmånligt alternativ.

Nyckelord: Elbilsladdning, Byggnadsautomationssystem, Smart byggnad, Smart laddning, Smart system, Fristående laddning, Fristående system, Belastningsstyrning, Allmän tariff, Spotpris

Preface

I want to give a big thank you to University Lecturer John Millar and to my instructor and colleague Tuomas Mattila for their excellent guidance and help that they provided me throughout this whole process. I also want to thank Schneider Electric for the possibility to write my Thesis for them. A sincere thank you goes also to my colleagues Aarni Falkman and Eero Pehkonen, who both used their own working time to give me valuable information and knowledge regarding my Thesis. A thank you goes also to my manager Toni Sisso who gave me his consent to work on the Thesis also during my working hours and to VP Kim Långström who gave me this subject about EV charging in buildings altogether. I want to also give a sincere thank you to our partner Plugit for all the data and knowledge they gave me regarding EV charging in both Sola and Ideapark. Without your help, I would not have been able to conduct my Thesis.

Furthermore, I want to thank my lovely family and all my friends who have taken part in my journey here in Aalto University. I am grateful to everyone who has helped me and encouraged me during my studies and this Thesis writing. Finally, a special thank you goes to Ville Luntinen who helped me, believed in me and supported me during this whole journey.

Otaniemi, 28.09.2019

Viivi J. A. Lemström

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Abbreviations

AC	Alternating current
BEV	Battery Electric Vehicle
BMS	Building Management System
°C	Degree Celsius
CB	Circuit breaker
CCS	Combined Charging System
CDR	Charge Detail Record
CEM	Clean Energy Ministerial
CO_2	Carbon dioxide
CPO	Charging point operator
CSV	Comma-separated values
DC	Direct current
EU	European Union
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GPRS	General Packet Radio Service
GPS	Global Positioning System
HVAC	Heating, ventilation and air-conditioning
IT	Information technology
LEED	Leadership in Energy and Environmental Design
LMS	Load Management System
MID	Measuring Instruments Directive
MPE	Maximum permissible error
OCPP	Open Charge Point Protocol
PHEV	Plug-in Hybrid Electric Vehicle
PME	Power Monitoring Expert
PWM	Pulse Width Modulation
RCD	Residual current device
RDC-DD	Residual direct current detecting device
RFID	Radio frequency identification
THD	Total harmonic distortion
SoC	State of charge
V2G	Vehicle to grid
VPN	Virtual Private Network

1 Introduction

The number of electric vehicles (EVs) has been growing at a steady rate since 2010 in the Nordics. Finland, among the other Nordic countries, has been able to reach one of the highest ratios of electric vehicles per capita in the whole world. The actual size of the EV market in the Nordics can be illustrated by the fact that after China and the United States, the Nordics came third in the sales volume of electric cars in 2016. The vehicles include battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and fuel cell electric vehicles (FCEV), of which the BEVs and PHEVs are the most common, and are referred to in this thesis.[4]

There are several initiatives that have affected the growth of the EV market globally. In 2015, almost 200 countries took part in a conference in Paris, where the Paris Agreement was drafted. The Paris Agreement is a world-wide commitment to combat climate change and accelerate a sustainable and low carbon future. The aim with the Agreement is to keep the temperature rise well below 2 degrees Celsius during this century to avoid drastic changes in our climate and ecosystems.[5] To achieve this goal, the reduction of emissions is crucial, and one way to do it is to move from conventional cars to EVs.

The EV30@30 campaign is another initiative that has strongly affected the growth of the EV market. The campaign was launched in June 2017 by the Clean Energy Ministerial (CEM) and the goal of the EV30@30 campaign is to reach a 30% market share of EVs among all vehicles by 2030.[6] The CEM is a partnership of 25 countries and the European Commission, which supports the deployment of clean energy and improvement of energy efficiency [7]. To contribute to this goal, several changes in regulations and taxation have been made in the participant countries. In Finland, which is one of the CEM members, both the vehicle registration tax and the road tax are currently based on the gCO_2/km (grams of carbon dioxide/kilometer) rating, promoting the sale of EVs. The highest vehicle registration tax rate, which is 50% of the import price, applies to vehicles that have emissions above 360 gCO_2/km and the lowest tax rate applies to zero-emission vehicles. To encourage the sales of EVs additionally, the lowest tax rate is going to be reduced even further from 3.8% to 2.7% in 2019.[4]

The EV30@30 campaign emerges from the will to reduce the greenhouse gas emissions coming from the transportation sector. The transportation sector is responsible for almost 25% of greenhouse gas emissions globally and is one of the fastest growing sectors when looking at the energy usage. These are the main drivers that has accelerated the electrification of this sector.[7] One of the main reasons why Finland supports the EV30@30 campaign is that it goes hand in hand with Finland's own energy and climate strategy for 2030. One of Finland's goals is to reduce 50% of greenhouse gas emissions emitted by the transportation sector by 2030. To achieve this goal, Finland has set a target to reach 250 000 electric vehicles during the next decade.[7] At the end of 2018, there were around 15 500 registered EVs in Finland, including full electric cars and hybrids, but it is estimated that by 2020 the number would be already 20 000 vehicles.[8] However, without implementing a huge number of EV charging stations, this estimate will probably not be realized. This has opened a competitive market for charging point operators (CPOs), such as Plugit, Virta and Fortum Charge & Drive, which offer both EV charging and the service around it. A result of this new competitive market is that there are already approximately 2 000 public EV charging points in Finland.[9] However, there is still a long way to go, since the aim is to have 25 000 charging points by 2030; one charging point per ten EVs.[4] The most convenient way to add EV charging points would be to install them next to buildings where people spend most of their time i.e. at homes, at workplaces and at stores. However, when looking for example at private chargers that are meant for homes, the chargers of the newest electric car models typically have a power rating of 3-7 kW (kilowatts). This adds a significant load to the household and if this additional load due to EV charging is not properly managed, the growth in the electricity demand can lead to exceeding the electricity connection limits of the house. This becomes even more essential when talking about business parks and shopping centers where several EV chargers are usually installed. Especially during peak hours and cold winter days, when the electricity usage is already close to its limits, this issue becomes urgent.[4]

The benefits of EVs are strongly dependent on the fossil fuel dependence of the power systems in different countries. In Finland, where almost 50% of the electricity is produced with renewable energy sources and around 30% with nuclear power, the benefits of EVs compared to conventional cars are high since the electricity used for manufacturing and powering the EVs is 80% carbon neutral.[10] In Norway, the EVs are also extremely beneficial for the climate, since over 95% of Norway's electricity is produced with hydro power [11]. However, for example in Germany and Poland, which are both still very fossil-reliant countries, the benefits of EVs are significantly smaller. The reason for this is that the EVs are manufactured and powered mostly with electricity produced with fossil fuels, which reduces the positive impact of EVs.[12]

Transportation is not the only sector that suffers from high energy consumption. The building sector is responsible for 36% of the total energy consumption globally and around 40% of the CO_2 emissions. It is estimated that the energy demand within the building sector rises by 3% yearly due to greater energy demand in developing countries, usage of high energy-consuming devices and higher energy demand coming from building construction sites.[13]

By using building management systems (BMS) in buildings, it is possible to control the energy usage and manage the loads in an effective way. The BMS can monitor and control, for example, lighting, HVAC (heating, ventilation and air-conditioning), lifts and elevators as well as, power, security and fire systems in the building. The BMS consists of both software and hardware, of which the software is used for monitoring and the hardware takes care of the measuring part by measuring, for example, temperature, air flow and humidity with different types of sensors. The obtained outputs can then be used to control the various quantities.[14]

The optimization of the energy usage in buildings is done through load management, which means both load reduction and load shifting [15]. In load reduction, the energy consumption is decreased, whereas in load shifting, the energy consumption may remain constant, but is instead shifted more equally throughout the day, reducing the consumption during peak hours.[16] One very important part of the load management is load modelling. Through load modelling, it is possible to predict load curves, which are time series of data collected by the BMS. By analyzing the load curves for different days, it is possible to understand how the building behaves and optimize the energy usage accordingly.[15]

To make the implementation of EV charging into buildings as smooth as possible, the additional loads from the charging need to be managed in a sufficient way, since the existing buildings are not planned to tolerate these additional loads. This could be realized by combining the data from building management system with the data gathered from EV charging. By combining BMS and EV charging in an intelligent way, the EVs could be charged in the most economic and optimal way by using the available energy resources efficiently and dealing with capacity restrictions at the same time.

Finally, people themselves, are very interested but also concerned regarding EV charging and its integration to buildings, which makes this research topical. For example, Facility and Property Managers are currently struggling with the issue regarding the buildings' electricity networks, which are incapable of withstanding the additional loads originating from EV charging. For this reason, it is worth studying if the EV charging could be optimized according to the buildings own electricity consumption without having the need of reinforce the electricity network in the buildings.

1.1 Research goals and research questions

One of the goals of this research is to find out if smart charging with smart building management system would enable integrating EV charging into commercial buildings without having the need of reinforce the building's own electricity system. Another goal is to find out if a smart system is more beneficial both in a technical and economic way compared to a stand-alone system. The third goal is to determine the technical prerequisites needed for integrating smart charging into smart buildings. To reach these goals, the aim is to answer the following research questions:

- What technical requirements are needed for implementing smart charging into smart commercial buildings?
- Can any technical benefits be achieved by combining smart charging with smart commercial buildings compared with stand-alone charging in commercial buildings without BMS?
- Can any economic benefits be achieved by integrating smart charging in different

types of smart commercial buildings compared with stand-alone charging in commercial buildings without BMS?

The purpose is to make it possible to implement the obtained methodology developed in this research to other commercial buildings.

1.2 Scope of the research

This thesis compares two scenarios within commercial buildings. The first scenario is a combination of buildings with an integrated smart energy management system together with smart EV charging. The second scenario studies the same buildings with stand-alone EV charging, but with the assumption that the buildings do not have an integrated smart building management system. In order to provide a clear comparison, this research will not cover smart buildings with stand-alone EV charging or buildings without building management systems with smart EV charging. The buildings include one office building with semi-public EV charging and one shopping center with public EV charging. The EV chargers in both cases are EV charging stations manufactured by Schneider Electric. The cloud based back-end system in both cases is provided and operated by Plugit.

1.3 Structure

This thesis consists of two parts. The first part creates the framework for this research, covering the definitions of smart and stand-alone EV charging and smart buildings. Different charging methods and charging equipment as well as various charging operators are discussed and a presentation of the building sector is made. Furthermore, different technical requirements as well as the electricity price and its components are defined. In the last part of the framework, the focus of this research is specified.

The second part is a research part which studies the implementation of both stand-alone and smart EV charging in two different commercial buildings. In the research material and methods section the different methods, methodological choices and research materials used in this thesis are described. The results section includes analysis of both economic and technical benefits that are possible to achieve by combining smart charging with smart commercial buildings compared with a stand-alone system. The technical requirements for implementing smart EV charging with smart commercial buildings are also reviewed for each case separately. Finally, in the discussion part the accuracy, reliability and the strengths of this thesis are discussed as well as some potential issues related to power quality and taxation. Some environmental aspects and opinions regarding EV charging and its integration to buildings are also lifted up. At the end the conclusion is drawn and some suggestions for further studying are presented.

2 Background for this research

This chapter is made up of six parts, and creates the framework for this research. The first part is a presentation of EV charging, which covers the most important aspects about stand-alone charging versus smart charging, alternating current (AC) charging and direct current (DC) charging, charging modes, charging connectors and different operators on the market at the moment. The first parts aim is to identify and become familiar with the different types of EV charging methods and equipment which are going to be studied in this research. The second part is a presentation of the building sector including an insight into different buildings and their energy consumption. In the third part, the concepts of smart buildings and building management systems are introduced and a connection between BMS and load management is made. The fourth part describes the technical requirements needed for implementing smart charging into smart buildings. In the fifth part, the electricity price and its components are studied to be able to understand what defines the price of the electricity and finally the last part defines where the focus of this research will be.

2.1 EV Charging

The transportation sector is responsible for almost 25% of greenhouse gas emissions globally and is one of the fastest growing sectors when looking at the energy usage. Global warming together with different political initiatives have accelerated the electrification of this sector, bringing battery electric vehicles and plug-in electric vehicles into great focus.[7] Because of this, EV charging has become a subject of intense studying, since the growth of the EV market is depending on the number of EV charging stations implemented.

An EV charging ecosystem consists of an electric vehicle, a charging station, a building connected to the charger and the utility side. In smart EV charging, a cloud based back-end system is also included in the ecosystem.[17] Through the back-end system, the charging can be monitored to make sure that no capacity limits are being exceeded [18]. Furthermore, the back-end system enables usage of payment services and it can control the availability and operation of the charging stations.[17] An EV charging ecosystem with a back-end system can be seen in Figure 1, where the cloud presents the back-end system and the arrows from the cloud the data flow between the vehicle and the charger.

There are several types of EVs on the market and how they are charged depends on the EV type. BEVs use only electricity coming from the grid as their energy source. The charged electricity is stored in a battery, which is used by an electric motor. PHEVs on the other hand use the electricity coming from the grid as their primary energy source but in addition, the vehicles are equipped with an internal combustion engine, meaning that they can drive on fuel too if needed. Charging of the EVs and especially BEVs, add significant loads to the electricity grid and if these loads are

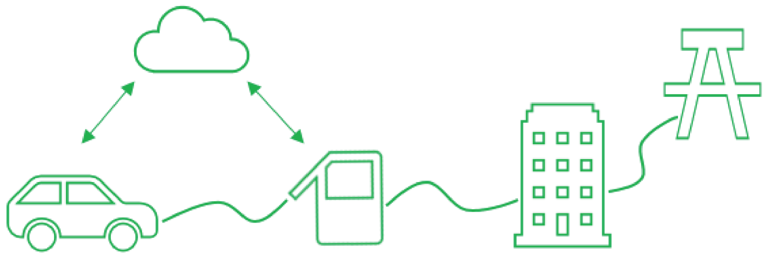


Figure 1: EV charging ecosystem.

not managed properly, the growth in the electricity demand can lead to exceeding the power limits of the distribution grid during peak hours.[19]

Depending on the location and usage of EV chargers, the charging can either be organized in a private, semi-public or public way. Private charging means that only the owners of the chargers can use them for charging their EVs. These chargers are commonly equipped with a lock to prevent unauthorized usage. Private charging is primarily meant for residential buildings and private parking areas, where only the people that have access to the property have the right to use the charger. Private charging comes usually without any payment service since the cost of the charging can simply be added to the users electricity bill.[20]

Semi-public charging is meant for office buildings and semi-public car parks. In semi-public charging, the users can be identified, to enable access only to those who have the right to use the chargers. How semi-public charging differs from private charging is that the users do not necessarily pay for the charging themselves but the company or owner of the car park takes care of the payment instead.[20] Furthermore, for charging at work places, a new taxation has been put into practice in January 2019. The owners of EVs can now pay a fee of 30 euro per month to be able to charge their EV at the work place unrestricted.[21] Another way is to pay only for the used electricity through identification and a billing service, which in most cases is going to be more profitable for PHEVs. For BEVs on the other hand, the fixed fee of 30 euros will most probably be the cheaper option, according to Schneider Electrics Business Development Manager Tuomas Mattila. The reasoning behind this is the differences between the battery sizes in PHEVs and BEVs, of which BEVs have larger batteries to be charged.[22]

The last way of organizing EV charging is by making the charging public. This means that anyone can access the chargers and charge their vehicles. Public EV charging can be found in public parking areas like shopping centers, gas stations or located next to driveways as on-street charging. Public charging can either be free of charge, which means that no identification is needed, or through registration and identification, meaning that the person using the charger pays for the electricity.[20]

Of these three ways of organizing EV charging, this thesis will be focusing on semi-public and public charging leaving out private charging. Furthermore, only those charging options which are connected to buildings are going to be studied. This leaves out EV charging in gas stations and on-street charging, which both are related to public charging.

2.1.1 Stand-alone charging versus smart charging

There are two different EV charging strategies in use; stand-alone charging and smart charging. The stand-alone charging's idea is that the owners of the EVs can charge their vehicles whenever they want without any restrictions. In stand-alone charging, the charging of the EV starts immediately when the EV is plugged in to the charger and lasts for the next few hours until the battery is charged fully.[18] When charging with a stand-alone charger, there is no control of the charging since the charger is not connected to any smart controlling system. This is a concern since it may result in very expensive charging bills because the charging may take place during the peak hours when the electricity prices are at the highest. It is estimated that the largest peak will be around 6 PM when owners of the EVs come home and start charging their vehicles at the same time. Behavior like this may result in loads that cannot be covered without turning additional power sources on, which in themselves are very expensive but also CO_2 intensive. Also, implementation of EVs in a larger scale, may require grid reinforcements which are expensive to be able to handle the peak loads.[19]

Smart charging on the other hand consists of an active charging management system with a hierarchical control structure. It controls and monitors the charging continuously making sure that no capacity limits are being exceeded.[18] The monitoring happens through a standardized communication link between the vehicle and the charger, which follows the SFS 6000 standard 722.3.5. The SFS 6000-7-722 standard is an add-on to the original SFS 6000 standard which is about low voltage electrical installations. This add-on was added in 2017 and it provides the most recent requirements concerning EV charging.[23] Furthermore, there is another communication link between the charger and the charging point operator, which enables control of the charging and making adjustments to the charging power in real time without interrupting the charging event.[24] This communication is done through OCPP (Open Charge Point Protocol), which is a open communication protocol meant for communication between the charging points and CPOs. There are several versions available of which OCPP 1.5 and 1.6 support the IEC 61851-1 standard, which is an international standard for EV charging.[25] In these two versions of the OCPP, two memory components has been added which enables CPOs to store authorized users and to operate and authorize users even if the communication would be temporarily lost [26].

As opposed to stand-alone charging, with smart charging the charging may not start immediately when the EV is plugged in, but instead when there is enough electricity available and the electricity prices are sufficient. In other words, with smart charging, the management system has the control and flexibility to charge the EVs throughout the whole time they are plugged in, instead of starting the charging automatically when the vehicles are connected, as in stand-alone charging. Therefore, with smart charging it is possible to use the available energy resources in the most efficient way, dealing with the capacity restrictions at the same time.[18]

2.1.2 AC and DC charging

The EVs can either be charged with alternating current (AC) or direct current (DC). Charging with AC is mostly referred to as slow charging and charging with DC is called fast charging. In slow charging, the current is converted with an AC-DC converter to DC, to be able to charge the battery, which requires direct current. In fast charging the conversion process in not needed, since the current is already in the correct form. The power in slow charging varies from 2,3 kW to 22 kW, while in fast charging the charging rate can go up to 50 kW and above. The charging current varies from 8 A (ampere) to 32 A in slow charging and in fast charging the magnitude of the charging current is over 100 A.[20]

The differences in the available powers and currents result in differences in the charging times. The charging time with slow charging varies from just under two hours up to 12 hours depending on the power rate and the battery size of the vehicle. In comparison, with fast charging the EVs can be charged fully in only half an hour. However, one notable thing is that it is not only the available power from the charging point that decides how long the charging time is. If the vehicle charger or the charging cable has a lower capacity rate than the power coming from the charging point, the EV cannot be charged with the full charging capacity. Instead, the EV is going to be charged with the capacity that the weakest part can bear.[20] The defining of the supportable power rate is done through handshaking between the vehicle and the EV charger. The plug has a pin called proximity pilot which measures resistance and determines the maximum current capability in the plug and the charging cable. It also analyses the physical connection between the EV and the charger by measuring voltage. The voltage on the proximity pin is higher when the vehicle not connected to the charger than when its charging.[27] Another pin on the plug called the control pilot specifies the allowed charging current according to the vehicle status. It uses a PWM (pulse width modulation) to determine the charging current based on the battery's state of charge (SoC) and temperature. Whenever either the SoC or temperatures changes, the charging current can be adjusted to correspond to the new conditions.[28]

The SoC and temperature of the battery affects the battery life. The battery should never be discharged fully since it reduces the battery life drastically. Also charging it to 100%, reduces the battery life. The reason to this is that the battery temperature rises higher when charged fully, which affects the battery performance in a negative way. The optimal is to keep the SoC between 25% and 85%, which doubles the battery life when compared with charging up to 100% but also gives an acceptable driving range.[29]

The charging can either be done with single-phase or three-phase power. In a single-phase AC power system, the power varies constantly meaning that during each cycle, the system reaches its peak value twice. The system is made up of one neutral wire and one phase wire. In a three-phase system, instead of one phase wire, there are three conducting wires with a phase shift of 120 degrees to each other. Due to the phase differences, the voltage on each phase wire reaches its peak at one third of a cycle before one of the other phase wires and one third of a cycle after the remaining phase wire. This results in a constant power transfer, which can carry more load than a single-phase system.[30] In a DC power system, the charging is for the most part done with three-phase power. When charging with a single-phase AC power system, the available charging power varies from 2,3 kW to 7,4 kW. By charging with three-phase power, the charging power goes from 11 kW up to 22 kW. Therefore, the choice of whether to charge with single-phase or three-phase power affects both the magnitude of the charging power and the charging time. The powers available for slow charging with their respective charging currents can be seen in Table 1.

Table 1: Powers for AC charging with respective currents.

	Power (kW)	Current (A)
single-phase	2,3	10
single-phase	3,7	16
single-phase	7,4	32
three-phase	11	16
three-phase	22	32

Finally, slow charging is mainly used in private and semi-public charging, where the capacities need to be quite low but where longer charging times are acceptable. Fast charging is usually used in public charging, where higher capacities can be handled and where it is more important that the charging times are kept short.[20]

2.1.3 Charging modes

Charging of the EVs can be done in four different modes of which the first three modes are slow charging modes and the fourth mode represents fast EV charging. Which of the four modes is used depends on the protection level of the charging and the equipment used for the charging. Mode 1 is EV charging with a simple cable through a domestic power socket. This mode has the lowest protection level and is not recommended to be used since there is a severe risk of overheating by not using dedicated charging equipment. Mode 2 charging is also done through a non-dedicated power socket, but unlike Mode 1, the cable in Mode 2 has a communicating device that monitors the charging continuously, which makes this mode acceptable to use. In Mode 3, a dedicated power socket is used for the charging together with a dedicated cable, giving the charging a high protection level being the recommended slow charging mode. In Mode 4, the charging is also done with equipment dedicated to EV charging and therefore this mode also has a high protection level.[20] The four different charging modes can be seen in Figure 2.

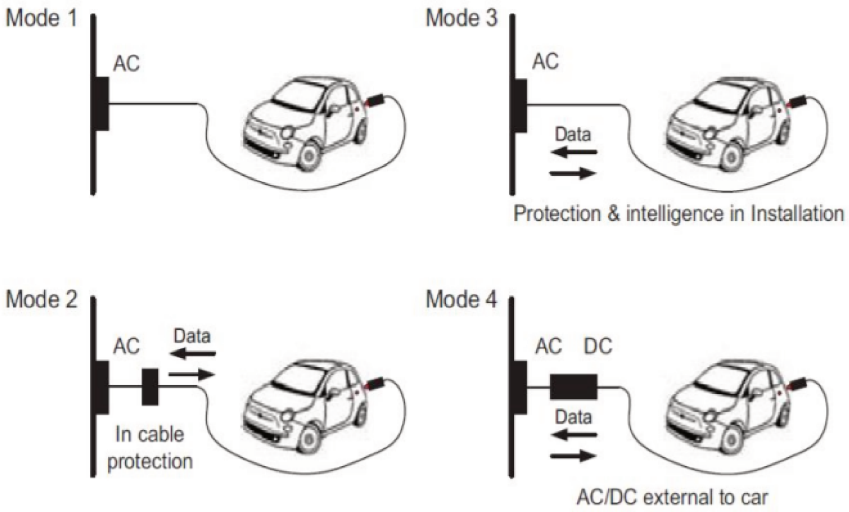


Figure 2: The four different EV charging modes.[1]

2.1.4 Charging connectors

The charging modes determine which type of charging connector can be used for the charging. The different connector types are standardized in IEC 62196-2. The IEC 62196 is a standard family defining requirements for connectors and socket outlets. In Mode 2 and Mode 3 charging, the accepted types are Type 1, Type 2 and Type 3. Connectors for Mode 1 charging are not listed since this mode is not recommended to be used. The Type 1 connector, also known as SAE J1772, is a single-phase charger, and is mainly used in the United States of America. The charging current of Type 1 is limited to 32 A. The Type 2 connector is designed by Mennekes, and is both a single- and three-phase charger. With the Type 2, it is possible to charge up to 70 A in single-phase and 63 A in three-phase.[31] The Type 2 charger is widely used in Europe and, in addition, the European Commission has decided that the Type 2 connector is the standard connector type in Europe. This means that all public AC charging stations must be equipped with a Type 2 connector or with a Type 2 socket outlet.[32] The Type 3 connector enables also both single- and three-phase charging. The Type 3 connector limits the charging current to 32 A in single-phase charging and to 63 A in three-phase charging.[31]

For Mode 4 charging, the standardized types of charging connectors are Combo 1, Combo 2 and CHAdeMO. The Combo 1 connector is a Type 1 connector with two additional pins for direct current. This enables both AC and DC charging with one single charging socket. The Combo 2 connector is correspondingly a Type 2 connector with two additional pins for direct current.[33] Another name for Combo 2 is CCS (Combined Charging System)[33] or SAE Combo.[2] Finally, CHAdeMO is a charging socket made in Japan, but it has managed to spread across the world to over 50 countries in 5 different continents. CHAdeMO enables charging with a power range of 6 kW up to 200 kW, and is also capable of bi-directional charging.[34] The Type 1 (SAE J1772), Type 2, Combo 2 (SAE Combo) and CHAdeMO connectors can be seen in Figure 3.

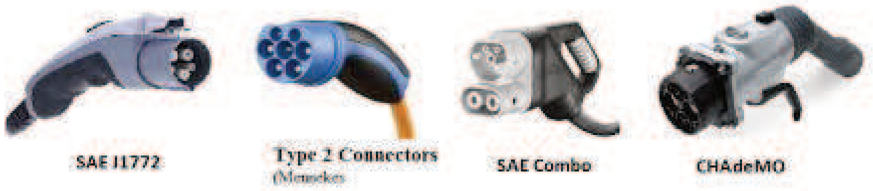


Figure 3: Type 1, Type 2, Combo 2 and CHAdeMO connectors.[2]

2.1.5 Charging point operators

There are several charging point operators in the smart EV charging market. The CPOs are business actors who offer charging points and take care of the maintenance and operation around them. To CPOs main tasks include purchasing electricity from suppliers and selling it to the customers. In some cases the energy companies also function as charging point operators. Furthermore, in many cases the CPOs take care of the e-mobility service too, which includes the payment system and communication between the vehicle, charger and the back-end system.[4] The communication between the back-end system, EV and the charger is important since it enables the usage of several tools, including user administration, reporting and remote control. User administration is about managing charging rights and being able to produce user-specific reporting from their charging history. Having reporting integrated to the back-end system, real time monitoring, historical data from charging events and reports from single chargers or charging point groups can be provided. Finally, with the ability of remote controlling, possible problems can be detected and, most importantly, solved without going on-site.[35]

The CPOs have many different pricing models in use for billing the customers. The two most common ways are to charge by used kWh (kilowatt hours) or per minute. Other pricing models are fixed monthly fees, payment per charging session or having no fee at all. Furthermore, the customers can decide if they only want to use one operator's charging points or be a customer for several operators. In Norway, for example, it is possible to register to several charging point operators at the same time with a universal charging tag. When charging with the tag, the customer is invoiced separately by each operator.[4] If the communication between the CPO and the charging stations would be lost, the transactions need to be queued and set on hold until they are authorized by the CPO [26].

One EV charging operator in Finland is Virta, which was founded in 2013 by 18 Finnish energy companies to accelerate the electrification of the transportation sector and combat the global warming. Virta does not only operate in Finland; its charging network is one of the largest in Europe. By registration, users can charge at all Virta's charging stations, but also on other operators around Europe through roaming. The charging service is offered with a card or a key that has radio frequency identification (RFID) implemented on it or with Virta's own mobile app. Any EV charger manufacturer can get their chargers to become a part of Virta's network by becoming a partner with Virta.[36] On top of the regular slow and fast charging stations, Virta owns also Finland's first vehicle to grid (V2G) charging station in Suvilahti. The charger is provided by Helen Oy, which is one of the owning companies of Virta. The V2G charger enables EVs to be used as energy storage units, which contributes to the balancing of the electricity network.[37]

Fortum Charge & Drive is Fortum's own charging network in the Nordics. It is especially designed to be used for public buildings and parking lots, but they also offer charging for private homes. In Finland, Fortum has already 200 chargers, which results in almost 400 charging points since almost all of the charging units are equipped with two socket outlets. Like with Virta, the charging service is offered either with a RFID-application or with a mobile app. In the Nordics, the number of chargers are around 1800, of which 600 are fast charger points.[38]

Plugit is another charging point operator in the EV charging business. Plugit was founded in 2012, and has been able to set a strong foot in the business in Finland by offering EV charging from households to large shopping centers. Like the other CPOs, Plugit does not manufacture the EV chargers, but uses partners to provide them. Plugit takes care of the installation process of the chargers, service and the payment methods. On top of that, Plugit also offers a customized cloud based back-end system, through which all the charging events are recorded. This allows customers to get all the data they need for their own activities.[39]

2.2 Building sector's energy consumption

The building sector is responsible for 36% of the total energy consumption globally and around 40% of the CO_2 emissions. It is estimated that the energy demand within the building sector continues to rise by 3% yearly due to greater energy demand in developing countries, usage of high energy-consuming devices and higher energy demand coming from building construction sites.[13]

It is not only the energy consumption that needs to be reduced. Also, optimization of load management in the buildings is crucial to meet the European Union (EU) Climate and Energy Objectives. These are reducing greenhouse gas emissions by 20%, increasing energy efficiency by 20% and increasing the share of renewable energy resources of total consumption by at least 20% by 2020. Within the building sector, the first two goals can be supported by making the buildings more energy efficient and by managing the loads in a flexible way.[14]

To be able to reduce the energy consumption within the building sector, it is critical to understand how the different buildings consume energy. Without knowing which assets consume energy and by how much, no improvements in electricity consumption and load management can be made. In the following sections the energy consumption within office buildings, residential buildings and shopping centers are described.

2.2.1 Energy consumption within office buildings

In office buildings, half of the energy consumed is used for heating, ventilation and air-conditioning. Another big source of energy consumption is lighting and office equipment, which are together responsible for 20% of the total energy consumption. Even though several techniques have been implemented during the last few years, including usage of LED's (light-emitting diodes), natural day light, passive cooling and passive solar heating, the energy consumption in office buildings is still high.[40] One reason behind this is an increasing trend within office buildings, where the buildings are not only used by people anymore. More and more high energy consuming IT (information technology) equipment, including computers, printers and servers, takes place in these buildings and increases the energy demand drastically.[41]

Furthermore, it is very common that the HVAC in office buildings are standardized to work during business hours from 6 AM to 6 PM. This kind of scheduling causes a significant energy loss since most of the employees do not arrive to the workplace before 8 AM or stay as long as to 6 PM at the office. This also concerns the IT equipment, of which a large part is left with power on even though they are not used. The same applies for lighting as well.[41]

2.2.2 Energy consumption within residential buildings

The energy consumption in residential buildings show a bigger variance than in commercial buildings due to larger differences in occupant behavior and the number of energy consuming devices per household. Despite this, residential buildings have a huge potential to save energy. Almost 30% of household energy consumption could be saved through a more efficient way of using the energy. In European countries, it is estimated that each household has the potential to save up to 1300 kWh yearly by making changes in behavior and using more energy saving devices.[42] These devices cover the usage of smart meters, smart appliances, home automation systems and by taking advantage of variable electricity tariffs. Smart meters save the households electricity consumption in a digital form and by that offer real-time information about the consumption. Smart appliances on the other hand are electrical household devices that have the ability to respond to signals coming externally. A home automation system is a smart system consisting of smart meters and smart appliances. By combining these together, the home automation systems can constantly monitor the energy consumption in the house and plan the usage of smart devices by taking advantage of the variable electricity tariffs. Variable electricity tariffs mean that the price per kilowatt-hour is not always the same but varies due to changes in supply and demand. The most common variable tariff is the day and night tariff, in which consumers pay two different electricity prices, one for the day and one for the night. The night rate is lower than the day rate since the electricity demand is lower during the night.[43]

2.2.3 Energy consumption within shopping centers

The energy consumption in shopping centers varies the most since the consumption is tightly connected to the number of stores and restaurants in the shopping center. The biggest energy expense in shopping centers is the HVAC, which is responsible for half of the energy consumption. Lighting consumes secondly most, and corresponds to around 30% of the energy consumption.[44] When looking at individual stores, these percentages vary substantially. For clothes stores, lighting is the biggest energy expense, and can alone consume up to 80% of the store's energy consumption. This is opposite to restaurants and coffee shops, where the energy usage is more concentrated around ventilation and air-conditioning as well as usage of electrical equipment such as stoves and ovens. Restaurants and coffee shops also consume overall more energy than regular clothes stores, which is displayed in the percentages of the total energy consumption in shopping centers.[45]

2.3 Smart buildings

To get rid of the energy waste in buildings, a concept called smart building, has been invented. Smart buildings are buildings integrated with a smart building management system consisting of both software and hardware. The software takes care of monitoring, whereas the hardware consists of different types of sensors giving various outputs. Typical sensors used in buildings are temperature sensors, CO_2 sensors, sensors monitoring air flow and movement sensors.[46] With the BMS, it is possible to monitor and control several energy consuming systems, for example, lighting, HVAC, lifts and elevators as well as power, security and fire systems in buildings.[14] By monitoring the energy usage closely, it is possible to find unnecessary energy expenses and by controlling different devices, the usage of energy can be optimized.

The energy optimization is done through load management. Load management includes both load reduction as well as load shifting.[15] In load reduction, the energy consumption is decreased where as in load shifting, the energy consumption may remain constant but instead shifted more equally throughout the day reducing the consumption during peak hours.[16]

Furthermore, load modelling is a very important part of the load management. Through load modelling, it is possible to predict load curves for the coming days. The load curves are time series of data collected by the BMS. The prediction of energy usage can either be done for short-term or for a longer period. Short-term load prediction forecasts energy usage up to one week ahead. Long-term forecasting can be done for months or up to even a few years ahead. Very short-term load prediction, which goes up to 24 hours, is important when considering the daily operations. It can provide a daily, hourly or even a half-hourly load prediction of peak loads and energy usage. By analyzing the load curves for different days, it is possible to understand how the building behaves and optimize the energy usage after that.[15]

2.4 Technical requirements

To be able to integrate smart charging into smart buildings, several technical requirements must be taken into consideration. Otherwise, it is not possible to integrate smart EV charging safely, efficiently and in accordance to building standards. In this section, the technical requirements needed for the integration is presented.

The first requirement is the smart building. As discussed in the previous section, smart buildings have BMS integrated in them making them intelligent. Together with the BMS and different sensors, the energy and power usage of the building can be monitored. By analyzing the data, the loads including EV charging can be managed in the most energy efficient way.[14]

Another requirement is the smart charging, which includes the cloud based back-end system discussed in Section 2.1 as well as load management functions. The communication between the charger and the back-end system can either be organized through Ethernet or wirelessly by using either WiFi or GPRS (General Packet Radio Service) such as 3G (third generation). If the communication happens through the Ethernet, an Ethernet cable is needed to connect the charger to the back-end system. If the communication is wireless, a router is needed to be able to connect the chargers to the cloud.[47]

The load management in smart charging, includes deferred start, current limitation and load shedding. The deferred start means that the EV charging does not start immediately when the EV is plugged in but instead when the electricity prices are below some predefined value or at a specific time that the owner or the user of the charger has decided. The deferred start enables EV charging when the electricity prices are at the lowest saving money. The second activity is the current limitation. Its idea is to limit the charging current to some specific value. When charging with 3,7 kW or 11 kW, the charging current is 16 A. Through current limitation the charging current can be set to 10 A to limit the used power to 2,3 kW and 7,4 kW respectively. When charging with 7,4 kW or 22 kW, the charging current is 32 A. By using current limitation, the charging current can be set to 16 A to reduce the charging power to 3,7 kW and 11 kW respectively. The last load management function in smart charging is the load shedding. This is important in EV charging installations where there is limited amount of current available for the charging. When the EVs come to the charging station to charge, they will get the maximum charging current available as long as the total current used for all EVs stays below the current limit. However, if the maximum amount of current is already in use to charge the EVs and an additional vehicle arrives to the charging point, load shedding occur. To be able to give electricity to all EVs, the charging current will be reduced for example from 32 A to 20 A for all vehicles. In other words, instead of not being able to charge one vehicle because of charging all the other EVs with maximum current, which would happen in stand-alone charging, all vehicles will be charged with a smaller current. The load shedding continues when new vehicles arrive to the charging station until the charging current for all vehicles is 14 A, which is the minimum three-phase current that is needed to start a charging event. For single-phase charging, the minimum starting current is 8 A. If a new EV arrives in this situation to the charging station and plugs in, the charger's load management system will stop the charging of one EV to give its charging current to the newest vehicle. The decision about which vehicle's charging to be stopped can either be done by checking the charging time or charged kilowatts. In other words, the charging will stop for the vehicle, which has been charged the longest time or received the most kilowatts. After 15 minutes, the load management system checks the situation, and possibly changes the vehicle which does not get charged. This procedure continues until some EVs leave the charging station or get fully charged and do not need the charging power anymore.[48] Another option would be to charge the vehicles accordingly when the cars are needed. If one vehicle would be needed in one hour and another one in two hours, the vehicle with a shorter charging time would get higher power. However, this alternative would require a possibility for the users to choose the charging time from the charger themselves, and this kind of function is not yet available in the chargers.

An example of the load shedding procedure can be seen in Figure 4. Each box represents one charging event and the colours, the time of charging with respect to the amount of kilowatts charged. The numbers in each box illustrates the charging current available for the EVs. In this example, the current limit is set to 100 A, which is the total maximum amount of current available for all EVs. Only the EVs which combined charging current is below the current limit can be charged. As seen in the Figure 4, after three EVs the load shedding sets in when more and more EVs arrive to the charging station. By the time the eighth EV arrives, no load shedding can happen anymore since the charging current is already at 14 A for each EV, which is the minimum three-phase current to start a charging event. Because of this, the load management system stops the EV, which has been charged the longest or received the most kilowatts from charging, to give its charging capacity to the newest vehicle. After 15 minutes, the system analyses the situation again and redefines which EVs will be charged and which ones not.

The EV charging stations can either be installed inside a building e.g. parking hall or outside in a car port or under the clear sky. However, not all chargers are suitable to be installed outside since they are not weatherproof, which needs to be taken into account when choosing the charger type. Furthermore, there are chargers that can either be installed on the ground or on the wall. Depending on the location of the charging stations, the selection of suitable chargers can be limited even further.

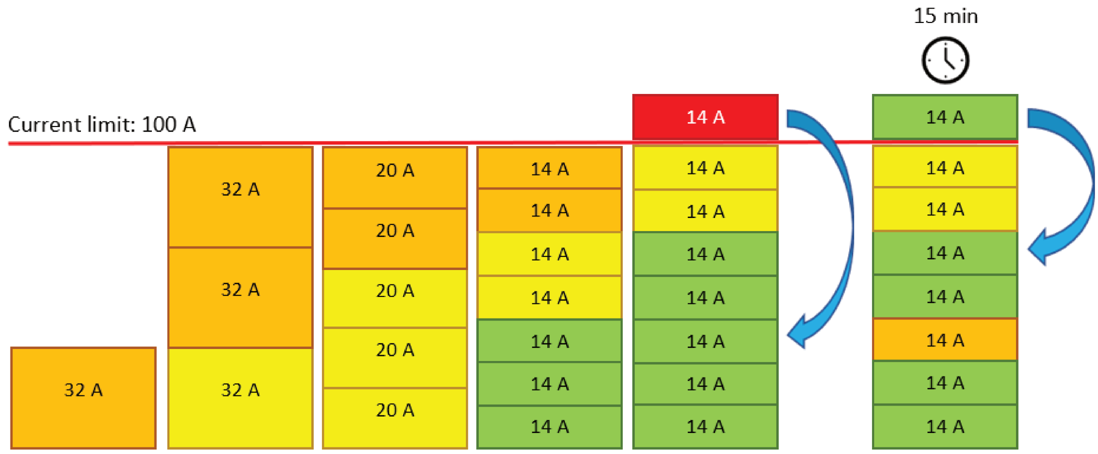


Figure 4: Load shedding in smart charging.

There are two standards that need to be taken into account when choosing the right charger. The first standard is SFS-EN 62262, which classifies the degree of protection of covers around electrical installations against mechanical impacts. In private charging, the minimum classification is IK07, which means that the charger can tolerate an impact of 2 J (joule). The highest rate is IK10, which tolerates an impact of 20 J. In semi-public charging the recommended classification level is IK08 and in public charging, the IK classification needs to be IK10 to protect the charger from vandalism. The other standard is SFS-EN 60529, which classifies the degree of protection that the cover of the electrical installation has against dust, water, intrusion and accidental contact. The minimum classification for charging stations located indoors is IP41 and outdoors IP44.[23]

The electricity for the chargers is usually taken from the buildings own electricity supply. In residential buildings, there is typically only one switchboard to take the electricity from. In bigger buildings such as office buildings and shopping centers, there are usually several main switchboards and smaller distribution boards. The capacity available at the switchboard or distribution board, determines whether or not EV chargers can be installed. If the existing capacity is not enough, a new distribution board needs to be built. Furthermore, the size of the main fuse determines the possible charging current that can be used for charging if the EV. In residential buildings, the most common fuse size is 3x25 A, which carrying capacity is 5,75 kW. In bigger houses also fuse size 3x35 A is widely used, which can carry up to 8,05 kW.[49][50] Currently, the biggest charging current available for charging is 32 A, which would require a main fuse of 3x63 A. The reason why 3x35 A fuse is not enough for the EV charging of 32 A is that the house has also other loads that need to be taken into account.[50]

The EV chargers can either be connected from the buildings electrical board with cables or using a busbar trunking system. Using cables are more traditional way to connect EV chargers to buildings and also a cheaper option when connecting five or less EV charging stations together. That is why the cabling suites well for small stand-alone charging systems. In bigger and especially smart installations a busbar trunking system for example Canalis is cheaper and more flexible option to use [51]. The Canalis is faster to install than traditional cabling and loads can be added or removed without interrupting the power supply. However, the Canalis can only be installed inside or outside under a shelter, which restricts its use, and a short cable is still needed to connect the Canalis to the electrical supply.[51] The economic differences in these two options have to be taken into account since the EU has published in 2018 their newest Energy Performance in Buildings Directive, which states that all new or renovated buildings with over 10 parking slots, need to have all of their parking slots prewired for the possibility of installing an EV charging station on each slot in 2021. Furthermore, 20% of parking slots of commercial buildings need to be prewired and equipped with at least one actual charging station.[52] In bigger installations the Canalis is a possible and worthy solution to meet these prewiring requirements.

To be able to connect EV charging stations safely to the building, protection for over current and short circuit is needed. A circuit breaker (CB) needs to be installed to each socket according to the SFS 6000 standard 722.532 to break possible fault currents. For chargers with charging current of 16 A, the CB needs to be able to break 20 A current and for chargers with charging current of 32 A, the breaking capacity needs to be 40 A. Furthermore, a residual current device (RCD) is needed to protect people against earth leakage current according to SFS 600 standard 722.531.[23] The RCD protects people against direct or indirect contact by disconnecting the circuit when detecting a leakage current. The RCD protects people also from fire hazard. There are different types of RCDs available but only Type A, Type A-Si (Super immune) and Type B of 30 mA can be used in protection related to EV charging. The RCD of Type A is able to detect AC residual fault currents. However, when charging the EV, there may be some DC leakage current and that is why the Type A needs also an residual direct current detecting device (RDC-DD) to be able to detect DC fault current above 6 mA. The Type A-Si is very similar to Type A but it provides better continuity of service since it is less sensitive for disturbances. The Type B RCD on the other hand, is able to detect both AC and DC residual fault currents and grants enough protection on its own. The disadvantage with the Type B RCD is that if it trips, an electrician is needed to restore the RCD. When compared with the Type A or A-Si, the tripping can be restored by pulling out the cable and putting it back again, which is much faster and cheaper way. However, the disadvantage with the Type An RCD combined with RDC-DD is that it trips already when detecting DC leakage current of 6 mA. This may be a problem when charging with old charging equipment or charging an older vehicle since the DC leakage current can exceed the 6 mA threshold and prevent the EV from charging entirely.[48]

When installing the chargers, phase rotation and phase balancing has to be take into account to avoid that all charging currents are on the same phase. In three-phase chargers, there are either 16 A or 32 A per each phase, whereas in single-phase chargers there is only 16 A or 32 A per one phase. To keep the total currents and the maximum power as low as possible, phase rotation has to be done with three-phase chargers and phase balancing with single-phase chargers. This means that L1, L2 and L3, which are the three different conductors in a three-phase system, are connected to the three different phases alternating and in a single-phase system, L1, which is the only conductor, is connected alternatively to the three different phases. Due to phase rotation and phase balancing, the loads are divided more equally per phase, which supports the electricity system all the way to the grid. In Table 2, an example of phase rotation and phase balancing can be seen. In this example, there are 6 charging points and two different EV models charging at the same time. The Renault Zoe is compatible with 3-phase charging of 32 A, while the Nissan Leaf can only be charged with single-phase power of 16 A. That is why the Zoe's uses all the three conductors with 32 A in each phase, whereas the Leaf's are only connected to the L1 with 16 A, leaving L2 and L3 without any current.[48]

Table 2: Phase rotation in EV charging.

	PH1	**PH2**	**PH3**
Zoe	L1 - 32 A	L2 - 32 A	L3 - 32 A
Zoe	L2 - 32 A	L3 - 32 A	L1 - 32 A
Zoe	L3 - 32 A	L1 - 32 A	L2 - 32 A
Leaf	L1 - 16 A	L2	L3
Leaf	L2	L3	L1 - 16 A
Leaf	L3	L1 - 16 A	L2
Total	**112 A**	**112 A**	**112 A**

With phase rotation, the total maximum current for each phase is 112 A and the maximum power becomes:

$$\frac{3 * 112\ A * 230\ V}{1000} = 77,3\ kW \tag{1}$$

With phase rotation and phase balancing, the phases would be balanced equally and the maximum power would be 77,3 kW. However, if the system is installed without phase rotation, it would result in an unbalanced system since the phase 1 would have 144 A and the two other phases 96 A, as seen from Table 3. Furthermore, without phase rotation, the maximum power becomes also higher as seen from (2).

$$\frac{3 * 144\ A * 230\ V}{1000} = 99,4\ kW \tag{2}$$

Even in a small system like this, the current difference between the two maximum currents becomes 32 A and the power difference 22 kW. These values corresponds to

Table 3: EV charging without phase rotation.

	PH1	**PH2**	**PH3**
Zoe	L1 - 32 A	L2 - 32 A	L3 - 32 A
Zoe	L1 - 32 A	L2 - 32 A	L3 - 32 A
Zoe	L1 - 32 A	L2 - 32 A	L3 - 32 A
Leaf	L1 - 16 A	L2	L3
Leaf	L1 - 16 A	L2	L3
Leaf	L1 - 16 A	L2	L3
Total	**144 A**	**96 A**	**96 A**

one three-phase charging point of 22 kW. In other words, without phase rotation, one three-phase charger should be uninstalled to reach the same values in both power and current than with phase rotation.

Finally, if the charging of the EV is invoiced, an energy meter needs to be installed next to each charger to meter the electricity consumption of the charging events. The energy meters must be MID (Measuring Instruments Directive) certified to be qualified to use as the base for invoicing. This concerns all energy meters used to invoice electricity, water, gas or heat consumption.[53] The MID is a directive set by the EU to standardize safety and performance specifications around metering equipment which are used within the member countries of the EU.[54] The MID includes different functional requirements [55] including a screen for the consumers to see the electricity consumption easily from [53], specific working conditions in variable environments, the maximum permissible error (MPE) that the meter can have from the correct value and allowable effect of different quantities that can influence the deviation of the readings.[55] However, the MID certification is only required when invoicing the electricity used for EV charging in kilowatt hours. If the EV charging is given as a service to the users or the pricing is time-based, no MID certification is needed for the energy meters.[56] Furthermore, if the EV charging is free of charge to the customers, no energy meters are required to be installed.

2.5 Electricity pricing

Both EV charging and buildings consume a significant amount of electricity. Because of this, it is very important to understand how the electricity price is formed and which components affect its magnitude. Without this knowledge, it is very difficult to reduce the electricity bill.

The electricity price is composed of three different components, which are energy price, distribution tariff and taxation. The energy price is the price of the actual energy that is produced by a supplier and consumed privately. The price of the energy is competitive, meaning that the consumers can choose from which supplier they want to buy the energy.[57]

In order for consumers to use the electricity, it needs to be distributed to them. This is the root for the distribution tariff, which consists of the transmission of electricity, the measurement of electricity consumption and the imbalance settlement. The distribution tariff is composed of a fixed monthly fee and of a fee that depends on the electricity consumption. Contrary to the energy price, the transmission price is not competitive, meaning that the consumers are forced to pay the transmission price to their local distributor. The transmission price is set up by the local distribution and transmission companies and it can vary significantly depending on the amount of consumers and the transmission distances by region. However, the Finish Energy Authority supervises the reasonableness of the transmission prices to keep them on acceptable levels.[58]

The third element which determines the electricity price is the taxation. Consumers must pay value-added tax both on the energy price and the electricity transmission service. On top of that, there is an electricity tax, which is invoiced in connection with the distribution tariff.[58] The electricity tax is divided into two categories depending on the electricity consumption. Low energy consumers which include residential buildings, service businesses as well as agriculture and foresting, pays a higher tax rate, as opposed to consumers with higher electricity demand such as industrial, mining and professional greenhouse cultivation, which have a lower tax rate.[59]

In most cases these three components are quite equally divided, meaning that each component corresponds close to one third of the total electricity price. In Figure 5, the electricity price components for Loiste, which is a Finnish energy company producing, selling and distributing electricity, can be seen [57].

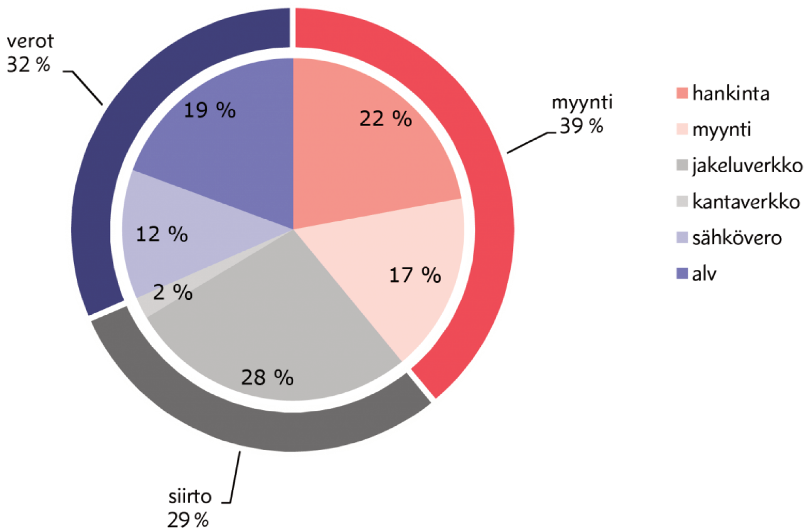


Figure 5: Electricity price components.[3]

In Figure 5, the red colour represents the energy price, which for Loiste is 39% of the total cost, the grey colour the transmission cost, which is 29% of the total cost, and the blue colour is the taxes, which forms the remaining 32%. When taking a closer look into these components, 22% of the total electricity cost comes from buying the energy from suppliers, 17% comes from selling expenses of the energy, 28% represents the distribution fee, 2% of the cost goes to maintaining the transmission grid, 12% represents the electricity fee, and the remaining 19% is the value added tax.[3]

2.5.1 Electricity tariffs

Electricity tariffs refer to the pricing of the electricity products. Understanding different pricing models is important, to be able to choose the one that is most cost-effective. The most common tariffs are general tariff, time of use tariff, seasonal tariff, power fee and spot price.[57] In the general tariff, the price of the electricity stays the same, regardless of day or time of the year. It is best suited for properties with low electricity consumption like apartments or low consuming office buildings. It also suits well for residential and row houses if they are heated by either oil, natural gas or district heating.[60]

Time of use tariff means that the consumers pay different prices for their electricity depending on the time of the day. It is made up of two different prices; one electricity price for day time consumption and one for the night time, where the night time price is lower than the day time price. It is best suited for consumers that consume over 10 000 kWh per year and who can concentrate their electricity consumption to night time. This tariff is most common in residential buildings that have electric storage heating, where the heater can be warmed up during the night of a considerably lower electricity price.[60]

Corresponding to the time of use tariff, the seasonal tariff also has two different prices for the electricity; one for the winter time and one for rest of the year. In this pricing model, the price for the rest of the year is less expensive than for the winter time and because of this, it is suited best for those whose consumption is higher during summer time. This tariff is mainly used among farmers that have mechanical hay or grain drying equipment.[60]

The power fee is meant for companies with high electricity consumption. How the power fee is determined depends on the energy companies. For example Loiste's power fee is determined by the average of the two month's highest average hourly power during the last 12 months [61] while for example the power fee of Caruna Oy is determined by the hourly peak power of each month [62].

Finally, in spot price the price of electricity is calculated separately for each hour. This means that the consumers always pay the current electricity market price.[57] Nord Pool is in charge of the biggest power market in Europe and offers both a day-ahead market as well as an intraday market for its customers. The actors on the spot market send their offers every day regarding how much they are willing to buy or sell and at which price. The price is then calculated from the supply and demand for each hour resulting in a variable electricity price.[63]

2.6 Focus of this research

In the previous sections, the background for this research has been established. This research studies both stand-alone charging as well as smart charging in commercial buildings. The commercial buildings studied in this research are one shopping center and one office building. The choice to study only commercial buildings was made to be able to study large EV charging systems instead of small EV charging systems with only one or two chargers as the situation is currently in most of the residential buildings. These two commercial building types enables to study both public charging as well as semi-public charging and the aim is to find out if the possible benefits achieved with the smart system differs depending on the charging application and the size of the EV charging system. In this research, a smart system refers to smart charging integrated to a smart building and a stand-alone system means stand-alone charging in a building without any BMS.

From the EV charging ecosystem in Figure 1, the EV charging station, the building and the cloud based back-end system are going to be studied. The EV and utility grid are left out from the scope. The EVs are not studied since this research is about charging an electric vehicle and not on the EV itself. The utility grid is left out from this research to be able to focus on how the EV charging affects the electricity consumption and capacity restrictions in buildings instead of how it affects the utility grid.

The EVs in this research will be charged only with AC and therefore, this thesis is focusing on slow charging, which will be referred as EV charging in the research part. This thesis will not study fast EV charging since slow charging is the most used charging method at the moment and it is mainly intended to be used with chargers that are connected with buildings where the owners of the EVs stays for a longer period of time. When it comes to the charging modes, Mode 3 will be used in this research. The reason for this is that Mode 3 is the only one of the slow charging modes that uses a dedicated power socket as well as a dedicated cable for the charging, and by that is the safest and most preferable slow charging mode. Since this thesis will be focusing on AC charging, only connectors for these modes are relevant. Since the Type 2 connector is mostly used in Europe, it is used to charge the EVs in this research.

Furthermore, the technical requirements for both buildings together with their EV charging stations are studied separately for both cases. Only the relevant technical requirements for each of the buildings and how the implementations are done in reality are discussed. Also, if some technical benefits are achieved by implementing a smart system instead of a stand-alone system, are they brought up and presented for each case separately.

Finally, when it comes to the electricity price and electricity tariffs, general tariff and spot prices are used in the calculations to find out if any savings can be gained from using a variable electricity price instead of a fixed one.

3 Research material and methods

In this chapter the the used research material and the different methodological choices made in this research are described. It also covers the way of carrying out this research as well as the used methods. The first part describes the research material used in this research which include information about the buildings and the EV chargers as well as determination of the electricity price which is used in the economic analysis. In addition, the load data from the buildings and charging data of the EVs are described. The second part presents the research methods used to analyze the benefits of combining smart charging together with smart buildings compared to stand-alone charging with buildings without BMS.

3.1 Research material

This section describes the research material used for studying EV charging and load management in two different commercial buildings. The research material is gathered from several places including the internet, Schneider Electric's own building management system, Ideapark's Facility Manager and Plugit. The studied material consists of data sheets, articles, catalogues, directives, standards and internet pages. Also some interviews and a survey are carried out to gather information and material for this research. The data analyzed is EV charging data as well as electricity consumption data from the buildings in several different formats. The EV charging data consists of information about the charging events including the used powers and energies for the charging, the start and stop times, and the average charging times. The electricity consumption data from the buildings include hourly resolution data of the building's electricity consumption.

3.1.1 The buildings

The commercial buildings studied in this research are presented in this section. The buildings analyzed are one office building and one shopping center. The buildings were chosen according to their type, their building management system and the number of EV chargers connected to them.

Office building
Sola Business Valley represents the office building in this research. It was built in 2012, and is located in Espoo. Sola is a rental building with a total floor area of 16 600 m^2. It is divided into three staircases, A-C, from which staircase C is studied in this research. The reason for this is that Schneider Electric is renting staircase C and that way has access to the energy data of that part of the building. On top of that, the EV chargers are located in the parking hall below the staircase C in Sola. Hereinafter, when talking about Sola in this thesis, it refers to the staircase C in the building.

Sola is a very energy efficient property, and received the LEED Gold-certificate (Leadership in Energy and Environmental Design) in 2013, being one of the first properties in Finland to earn it. The Gold-certificate includes a 34% reduction in water consumption and 29% reduction in energy consumption.[64]

Shopping center

Ideapark represents the shopping center in this research. It was opened in 2006, and is located in Lempäälä. In 2018, 15 000 m^2 addition was opened resulting that Ideapark became one of the biggest shopping centers in Finland, having an area of over 100 000 m^2.[65] Ideapark provides floor space for over 150 stores and restaurants which around 7 million customers visit yearly.

Ideapark is one of the most energy efficient shopping centers in Finland, having around 80% less heat consumption as an average shopping center according to Motiva. Furthermore, Ideapark's electricity consumption is 22% less than average, resulting in over 50% reduction of CO_2 emissions. The energy savings have been possible to achieve through energy metering, lighting control, energy conservation and technical facility management, which together has reduced the operational costs by 40%.[66]

3.1.2 Electricity price

To be able to know how much it costs to charge the EVs and how much the studied buildings pay for their electricity, the price for the electricity needs to be known. Two different tariffs are going to be used in this research which are general tariff and spot price. The general tariff is calculated from monthly averages of Nord Pool Elspot Day-ahead market prices in Finland.[67] Price data from the previous four years (2015-2018) is used in the calculations in order to minimize the deviations in energy prices. The average monthly energy prices for Finland during the previous four years can be seen in Table 4. The energy prices are presented in EUR/MWh (euro/megawatt hour).

When looking at the energy prices in the Table 4, during 2018, the prices have been significantly higher than during the previous three years. The reason for this was the hot and dry summer in 2018, which affected strongly water levels in hydro power plants. Because of this, the hydro power plants needed to limit their production, which affected the spot prices in a negative way. Also the nuclear plants had to restrict their production to be able to keep the temperature of the drain water in the cooling system within the limits of plant's permits. The shortage of electricity in Finland resulted in exporting electricity from Germany through Sweden, which increased the prices further. On top of that, the electricity price in Germany was also high because of low water levels in rivers due to the hot and dry weather. This resulted in producing electricity with coal in Germany instead, which was costly due to the high price of coal. The prices remained exceptionally high also the rest of the year due to the cold and dry autumn, which continued to affect the production of hydro power and kept the prices high.[68]

Table 4: Average monthly energy prices in Finland.

	2018	2017	2016	2015
Jan	37,08	33,29	37,83	33,80
Feb	43,36	35,07	26,09	33,18
Mar	45,60	30,68	27,09	29,42
Apr	40,21	31,40	27,25	30,09
May	38,63	30,67	28,06	25,87
Jun	47,17	30,64	35,41	21,52
Jul	54,00	34,17	30,97	27,57
Aug	55,48	36,28	31,38	31,12
Sep	51,00	37,27	32,52	31,75
Oct	46,36	33,42	37,54	33,49
Nov	50,08	33,67	41,02	31,74
Dec	52,32	31,92	34,00	26,56

The energy price corresponding to the general tariff is calculated as an average of the values in Table 4. The average price is 35,52 EUR/MWh, which corresponds to 3,552 c/kWh (cent per kilowatt hour). On top of the energy price, the electricity tax is included. It is 2,79372 c/kWh for residential and commercial buildings and 0,87172 c/kWh for industries.[59] This gives an electricity price of 6,34572 c/kWh for the buildings and 4,42372 c/kWh for the industries. For residential and commercial buildings, this electricity price is around 1 c/kWh more expensive than the lowest electricity price available for consumers. The main reason for this is the high electricity prices during 2018, which increased the result from the calculations. However, the electricity price for the buildings falls well in line with the current electricity prices at the market and can therefore be used to calculate the energy expenses in the economic analysis.[69] Additionally, the distribution tariff is included in the electricity price. The transmission price is determined by the local distributor. For Sola, which is located in Espoo, Caruna Espoo Oy is responsible for the electricity distribution. Caruna's price for the transmission is 3,14 c/kWh with a monthly fixed fee of 5,90 €.[70] Ideapark, which is located in Lempäälä, has Elenia as their distributor. Elenia's transmission price is 7,53 c/kWh, with a monthly fixed fee which depends on the size of the main fuse.[71]

The spot prices to this research are taken from Nord Pool Elspot Day-ahead market prices in Finland. Four days price data were collected to see how the prices vary between different days.[72] All four days are winter days, since during the winter, the electricity consumption is usually higher than during the summer and therefore more price sensitive. The hourly spot prices for the different days chosen can be seen in Table 5. The prices are in EUR/MWh. One day from 2018 is taken as a comparison to see how the energy price has been the previous year. January 24th, 2019 is taken as an example of an extreme case where the energy price was more than double during the peak hours. The hourly prices are used in the economic analysis to see if any savings can be gained from using a variable electricity price in the different cases.

Table 5: Hourly energy prices in Finland during winter time.

	14.01.2018	18.01.2019	24.01.2019	18.02.2019
00-01	28,90	46,22	55,98	40,38
01-02	28,44	44,05	55,80	38,78
02-03	28,06	43,90	55,57	38,78
03-04	27,97	44,07	55,33	38,20
04-05	27,87	48,25	55,80	40,46
05-06	28,01	50,30	60,05	43,66
06-07	28,35	52,74	75,98	47,92
07-08	28,55	53,94	96,70	47,29
08-09	28,83	54,42	109,45	46,60
09-10	29,41	55,62	107,67	46,54
10-11	29,74	55,00	98,06	46,41
11-12	30,13	55,35	100,37	45,09
12-13	29,81	56,14	95,18	44,15
13-14	29,44	55,02	89,67	43,97
14-15	29,94	56,68	87,70	44,78
15-16	31,32	57,33	88,28	45,55
16-17	33,27	59,53	95,01	46,03
17-18	33,98	59,80	106,82	47,32
18-19	32,50	58,06	100,29	47,85
19-20	31,38	53,85	73,38	45,35
20-21	30,55	53,05	60,35	44,80
21-22	29,69	52,75	59,75	43,98
22-23	29,33	51,19	58,45	42,23
23-00	28,82	50,03	57,19	39,21

In some situations, the consumer also needs to pay charges for reactive power and reactive energy. Reactive power is generated from inductive and capacitive loads. By utilizing compensation, it is possible to stay within the limits for reactive power and avoid the reactive power charges.[57] This research assumes that the buildings studied do not exceed the limits and that reactive power or reactive energy charges do not need to be taken into account in the calculations.

3.1.3 Electricity consumption data from buildings

This section describes the electricity consumption data coming from the two commercial buildings. The obtained load data contains the electricity consumption of the basic loads which includes heating, cooling, air conditioning, lighting, and electrical equipment. The data range, format, amount and level of detail varies depending on the building in question.

Office building

Sola has a BMS integrated in it called Power Monitoring Expert (PME). The PME is Schneider Electric's own BMS, which monitors the power and energy usage in the building. The PME measures the energy consumption in Sola in real-time and stores the data for several years. The total yearly energy consumption in Sola is around 1,31 GWh (gigawatt hours). The lighting consumes around 9% and the office equipment almost 17% of the total energy consumption yearly. Together they are responsible for 26% of the total energy consumption, which stays well in line with the average share of 20%, which was discussed earlier in Section 2.2. Furthermore, the air conditioning corresponds to 23%, cooling 10% and heating 14%. The heating includes both space heating and the heating of the car ramp to the parking hall. Together, they are responsible for 47% of the total energy consumption, which also stays well in line with the average share of 50%. The rest of the electricity is used by outdoor lighting, by the car heating poles outside the building and to operate three elevators inside the building. The electricity used for charging the EVs is not included in the yearly energy consumption since the EV charging stations were only installed in the beginning of 2019 and there is no charging data for a full year available. The distribution of the energy consumption in Sola can be seen in the Figure 6.

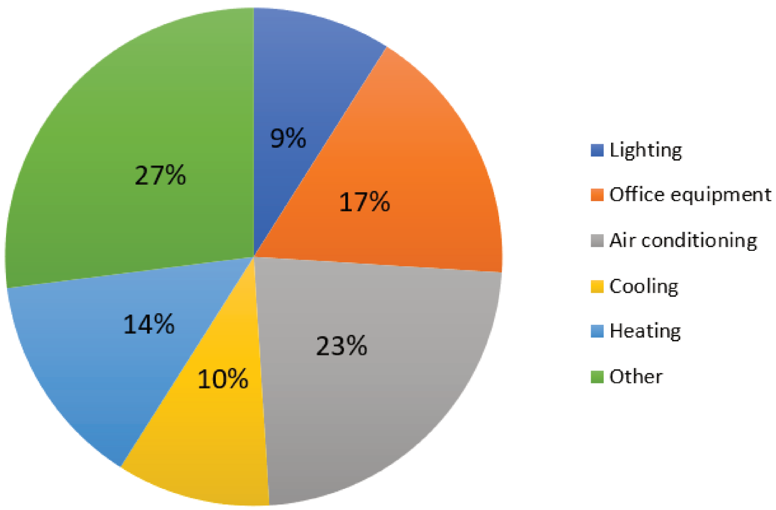


Figure 6: Energy consumption in Sola.

The energy consumption varies drastically depending on the time of the year. During summer time, the energy consumption is much lower than during the rest of the year. The main reason to this that people are on vacations and less lighting and heating is needed during the summer months. From the individual load consumption, the heating and cooling varies the most during the year. During the winter, heating is around 20% and cooling under 5%. At summer, the ratio is the other way around.

Shopping center

The electricity consumption for Ideapark was given by Ideapark's Facility Manager Tommi Isomäki. The consumption data is provided in an Excel-format, which shows hourly consumption data from April, 2019, including information about outside temperatures. The monthly electricity consumption for Ideapark can be seen in Figure 7.

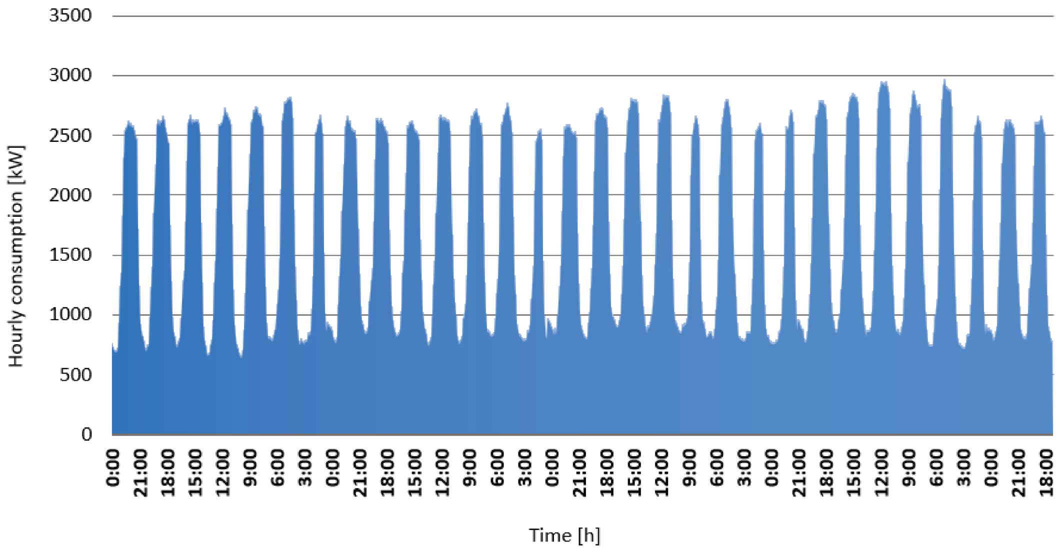


Figure 7: Energy consumption in Ideapark.

The hourly data varies from 656 kW all the way up to 2 972 kW, being lowest during nighttime and highest at daytime. The daily electricity consumption is on average 41 000 kWh, resulting in a total monthly electricity consumption of 1,23 GWh. This is close to Sola's yearly consumption, which shows how much more electricity a big shopping center consumes compared to a mid-sized office building. In a year, Ideapark's total electricity consumption becomes around 14,8 GWh. Furthermore, Ideapark's consumption is not strongly affected by the outside temperature. For example the first 12 days average temperature in April was 2°C (degrees Celsius) and the average consumption was 1 742 kWh. During the following 12 days, the average temperature was significantly higher being 8°C, but the average consumption was nearly the same being 1 710 kWh. Of course from these results it is impossible to say how the situation would be if the comparison would be done for example between a cold week during the winter and a warm week during the summer, but at least in a small scale, the outside temperature does not affect the electricity consumption in Ideapark.

3.1.4 EV chargers

The EV chargers studied in this research are manufactured by Schneider Electric. Schneider Electric is a global French company, which is specialized in energy management and automation.[73] Schneider Electric's EV charging product family is called EVlink, and it includes AC chargers for private, semi-public and public usage. The chargers charging capacity varies from 3,7 kW to 22 kW and the charging current from 16 A to 32 A depending on the charger.[20] In this research, EV chargers for semi-public and public charging are going to be studied.

Office building

There are 14 charging stations with one charging point each in Sola's parking garage where they were installed in January 2019. The chargers are EVlink Smart Wallbox charging stations, which are three-phase chargers with a maximum charging power of 22 kW and maximum charging current of 32 A. These chargers are intended for semi-public usage and that is why they were chosen to Sola. The chargers are rented by several companies which is why the chargers are equipped with user identification and with different functionalities depending on the wishes of the company that uses them. The user identification ensures that only the employees that are entitled to the chargers gets to charge with them. The chargers technical characteristics can be found in Appendix A.

Shopping center

Ideapark has 20 charging stations with two charging points each resulting in a total 40 charging points. The chargers are EVlink Parking charging stations, which are meant for public usage. The chargers were installed in August 2018 and they are free of charge for Ideapark's customers. Because of this, the chargers do not have user identification included in them. The chargers are three-phase chargers with maximum charging power of 22 kW and maximum charging current of 32 A. The technical characteristics for these chargers can be found in Appendix B.

3.1.5 Charging data from buildings

Charging data for analyzing the charging of EVs for the office building is taken to some extent from the PME and an overview of the charging events is provided by Plugit. The EV charging data for the shopping center is provided entirely by Plugit. In this section the electric system behind both building's chargers are also described since the electrical system limits the possible charging powers and currents having an affect on the whole EV charging system.

Office building

Sola's electricity is supplied by two main switchboards, PK1 (pääkeskus 1) and PK2 (pääkeskus 2). The chargers in Sola are behind a distribution board called nousukeskus (NK), which is located behind PK1. From the NK goes 10 outputs, of which 8 are in use and two outputs are spare. The EV chargers are behind the eighth output, named NK_8Q1. The current limit for the EV charging system is at the moment 160 A, meaning that no more than 160 A can be used simultaneously for EV charging to not exceed the capacity limit of the NK.

The amount of electricity used to charge the EVs can be seen from the PME, which monitors the energy demand of the NK_8Q1. The data is extracted from the PME to Excel for analysis. More detailed information about the charging events is provided by Plugit as an .js (JavaScript) file, which shows the number of charging events, used charging powers and energies, duration and start and stop times for the charging events.

Shopping center
The chargers in Ideapark are powered by a substation located next to the chargers. The current limit for the whole EV charging system in Ideapark is set at 400 A since it is the maximum current available from the substation. The 20 chargers are grouped in four groups with 5 chargers and 10 charging points each. For each group the maximum current limit is set at 160 A, which would result in a total maximum current of 640 A if all 40 charging points would be in use simultaneously. Due to this, Ideapark needs to have a smart LMS (Load Management System) to control the charging in order to not exceed the maximum limit of 400 A even if all chargers would be in use.

Detailed information about the charging events is provided by Plugit. The charging data consists of all charging events occurred in Ideapark from January to May in 2019. The data is provided in a .numbers file, which is Apple's own spreadsheet and it consists of a list of all the charging events with information of their duration, used powers and energies and the time of the day of the occurrence. An overview of the charging events over a longer time period is also provided by Plugit in a .js file. This data consist of charging information from July 2018 to the end of March 2019 including the number of charging events in total and per week day, the number of started and stopped charging events by hour, the average amount of energies and charging powers used, and the average duration of the charging.

One notable thing in Ideapark's case is the Energy Performance in Buildings Directive lifted previously in Section 2.4, which requires that 20% of the parking slots of commercial buildings are prewired in 2021. There is 4 000 parking slots at the moment in Ideapark meaning that up to 800 parking slots should be prewired during the following two years, which is an enormous investment. This will also have an effect on Ideapark's current electrical system, which will require some changes because of this.

3.1.6 Survey

To understand what the building owners and facility managers think about EV charging and its integration to their buildings, a survey was conducted for them. The survey was made as a Webropol survey with 18 questions of which 17 were specific questions and one an open question. The first three questions in the survey are general questions to get to know the respondents and the rest of the questions are related to EVs and EV charging. The last question is an open question about what thoughts the increasing amount of EVs evoke. The survey was sent by email to over 400 Facility and Property Owners and Managers in July 2019, and received 111 answers. All the questions together with the answers can be seen in Appendix E except for the answers for the last question, which was the open question. Instead, its answers are discussed in Section 5.1.5. The survey was originally made in Finnish but it is translated to English to be able to attach it to this research.

3.2 Research methods

In this section the research methods used and the methodological choices made in this thesis are described. This research is a mixed case study, involving both qualitative assessment and some quantitative analysis. It studies commercial buildings of two different types with integrated EV charging. For each building, both smart and stand-alone EV charging are studied as two separate cases. The choice to study commercial buildings of two different types was made to be able to focus properly on both ways of organizing the charging in these building types i.e. in a public and semi-public way. The reason to study only one building of each type is to be able to focus properly on each case and gain a deep understanding of the factors affecting the integration of EV charging into the different buildings in question.

This research utilizes heuristic technique where the analysis for both buildings is done through experimentation based on real data. For both cases, the optimal way of organizing the charging with both smart and stand-alone chargers is calculated by hand to find feasible results that satisfies the existing constraints in the buildings and their EV charging system. Excel is used as a tool to analyze the data, create graphs and as a help to perform the calculations.

The electricity consumption data is analyzed first for both buildings after which the EV charging data is included in the analysis. After the data analysis is completed for both stand-alone charging and smart charging, an economic analysis is conducted. In the economic analysis the costs for both the stand-alone system and smart system are analyzed and the results compared with each other to find out if any savings can be achieved with the smart system. In the economic analysis regarding the spot prices, only a limited selection of days is chosen to be used in the calculations. The small selection of days results to a manageable amount of data, which can be utilized with the heuristic technique. Although the amount of days are limited, they are still able to show how much the spot prices can vary both during a short and long time interval.

Interviews were also conducted to gather information about the buildings and their charging infrastructure to make the analysis possible. In Sola's case, both Schneider Electric's and Plugit's employees and experts were interviewed to learn about the electrical system and charging system in Sola. Also in Ideapark's case, Plugit's experts were interviewed to gather information about Ideapark's charging system. Loiste's Business Manager Tommi Göös was interviewed to learn about the different tariffs and what affects the electricity price to be able to conduct the economic analysis.

Finally, a survey was conducted to Facility Managers and Property Managers to get a general view and an opinion of what they think about EV charging and its integration to buildings. The aim with the survey was also to validate the importance of this research with opinions and views from those who make the decisions to purchase EV chargers and integrate them to the buildings. The survey received 111 answers, giving valuable information about property owners' and managers' views and opinions regarding EV charging and its integration to buildings. The results of the survey are presented in Section 4.6 and discussed in Section 5.1.5.

4 Results

In this section, the results of this research are presented and discussed. In the first part, the data analysis is performed. Both load data from the buildings as well as charging data, which includes used charging powers, charging times, number of charging events and used energies, are studied. In the second part an economic analysis is executed for both buildings according to the data analysis conducted in the first part. The third part addresses the technical requirements needed to implement smart charging into the two different buildings studied. The fourth part shows what kind of technical benefits can be achieved by combining smart charging with smart buildings. In the fifth part the economic benefits achieved by integrating smart charging to the different buildings instead of stand-alone charging are discussed and in the last part the results of the survey are presented.

4.1 Data analysis

In this section, the data and material obtained for the two cases are analyzed. For each case, the electricity consumption for the buildings is studied. Only the relevant hours for each case are taken into account in the analysis. Furthermore, both buildings EV charging is examined. From the EV charging data, two charging models are created for both cases, of which one is with stand-alone charging and the other one with smart charging.

Office building

The load data for Sola is extracted as a comma-separated values (CSV) file from the PME and converted to a more readable format with Excel. The data analyzed in this research is yearly energy data from 2018, hourly energy data during weekdays in 2019 and charging data during 2019. The charging data includes used charging powers, charging energies, stop and start times as well as duration of the charging events. With the PME it is also possible to analyze the power quality, which can be negatively affected by EV charging, since it is a non-linear load. Insufficient power quality can lead to failures in electrical equipment and in the electrical system and therefore the power quality needs to be examined when discussing about EV charging. In Section 5.1.2 a power quality analysis for both Sola and Ideapark is carried out.

Sola's average electricity consumption during the working hours can be seen in Figure 8. The data is gathered during March 2019 and only weekdays and hours between 6 and 18 are taken into consideration. The reason for using only weekdays and the time interval in question in this research are that during these times, most of the employees and staff are in the building consuming electricity and during weekends, evenings and nights, the building is practically empty.

From Figure 8, it is possible to see that the employees start arriving to work around 7 o'clock, since the electricity consumption increases drastically from the previous hour.

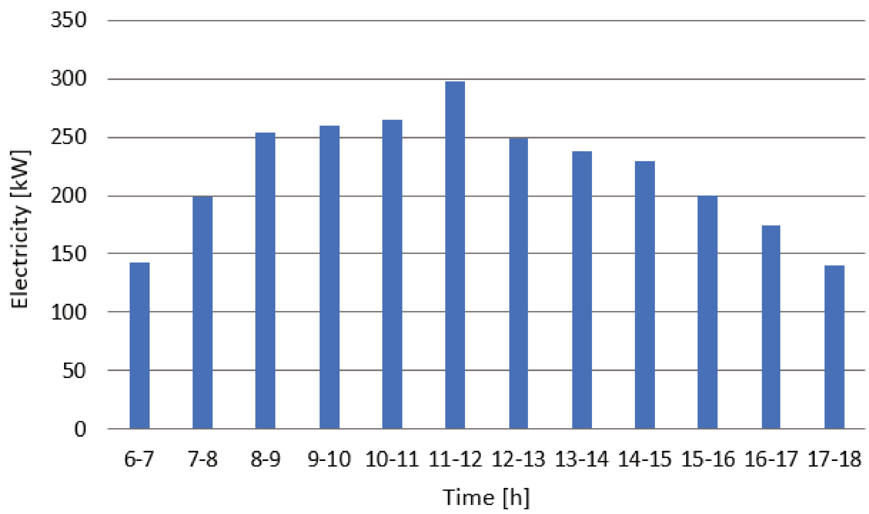


Figure 8: Sola's hourly electricity consumption during working hours.

The same occurs between 8 and 9, as a result of most of the employees arriving to the workplace. The peak hour is from 11 to 12 o'clock, where the electricity consumption reaches close to 300 kWh. The logical explanation to this is that the canteen with its ovens, stoves, ventilation and air-conditioning is running at full speed around midday. After lunch, the electricity consumption starts to decrease a little by each hour, and slightly more sharply when reaching 15 o'clock when employees start to leave work. After 17, the electricity consumption has reached the same level as it was between 6 and 7 in the morning, which is the base consumption for Sola. From this graph, the ideal EV charging times would be between 6 and 8 and 15 to 18, since the electricity consumption is lowest during these hours leaving an acceptable amount of capacity to be used for EV charging. However, in general most of the employees work between 8 and 16, meaning that the EVs would only have time to charge between 15 and 16 which is not enough. That is why the EV charging could take place between 6 and 11, then stop for one hour and continue again at 12, leaving out the hour with the highest consumption.

The EV charging data for Sola is also taken from the PME. The PME gives the amount of energy used for the EV charging in 15 minutes intervals. More detailed information about the charging is provided by Plugit and their back-end system. In 2019 from January to the end of March, 303 charging events have taken place in Sola. The average charging time has been close to 7,5 hours but the charging times varies all the way from 20 minutes to almost 10 hours. The average charging capacity has been 6,40 kWh. All the charging events can be seen in Figure 9. The blue columns show all the started charging events and the red columns all the ended charging events with corresponding hours.

From Figure 9, it is possible to see that the first EVs arrive at Sola around 7:00 in the morning and the last EVs leave around 19:00 in the evening. However, most of the charging events start around 9:00 in the morning and end around 17:00 in the

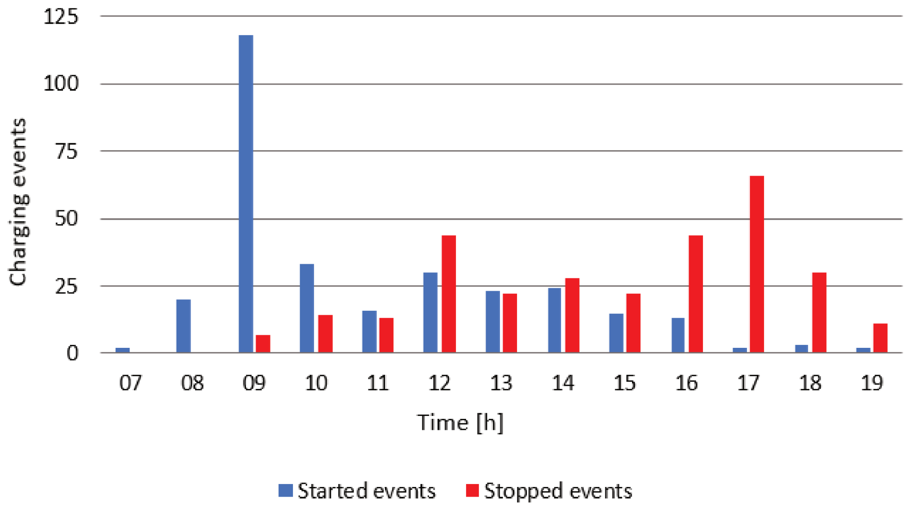


Figure 9: Charging events in Sola.

afternoon meaning that between these hours, most of the charging events take place. Currently, the maximum simultaneous energy used for charging has been almost 30 kWh, but only half of the chargers have been used simultaneously. The maximum energy will be higher when all 14 charging stations are in use at the same time.

On average, small EVs have a battery size between 12 and 18 kWh and mid-sized vehicles a battery of 22-32 kWh. However, the largest EVs can have a battery up to 100 kWh, which needs to be taken into account in the analysis.[74] The aim is to organize the charging in such a way that the EVs can be charged during their owners working day from a SoC of 20% up to a SoC of at least 80%, or according to how many kilometers they need to drive after work. With a large battery of 50 kWh, this means 30 kWh of charging to get from 10 kWh to 40 kWh. Furthermore, statistically, Finnish citizens drive on average between 40 and 50 km per day, of which 10 to 30 km is used for driving to and from work.[75][76] The goal is to organize the charging so that all EVs are able to drive 50 km after the working day to be able to drive via stores or hobbies, for example, before arriving home.

On average, EVs consume 0,18 kWh/km [48], which means that an EV charged at 22 kWh/h, needs only to be charged for 25 min to be able to drive 50 km as seen from (3).

$$\frac{0,18\ kWh/km * 50\ km}{22\ kWh/h} = 0,41\ h = 25\ min \tag{3}$$

Similarly, with a charging rate at 7,4 kWh/h, the required charging time is already over 1 hour and if only 3,7 kWh/h of energy is available, the charging time for 50 km is 2,5 hours. Furthermore, to be able to fill an EV with a large battery of 50 kWh from empty to 100%, it takes 2 h 16 min if charged with 22 kW as seen from (4). If the EV can only receive for example 7,4 kW or 3,7 kW, the charging time to reach a battery level of 100% is around 6 h 45 min and 13 h 30 min respectively.

$$\frac{50\ kWh}{22\ kW} = 2,27\ h = 2h\ 16\ min \tag{4}$$

One other important aspect to take into account when organizing the charging is the charging current limit of 160 A that exists in Sola. If, in each of the 14 charging stations, three-phase charging would take place, the maximum current for each phase would be 448 A, which is almost three times the existing current limit. Taking phase rotation and phase balancing into account, with the current system it would be possible to charge either 5 EVs at 32 A, 4 EVs at 32 A and 6 EVs at 16 A, or 3 EVs at 32 A and 11 EVs at 16 A. The last option is the optimum way of organizing the charging since all the charging stations could be in use at the same time without exceeding the current limit. In Table 6 is shown how the charging could currently be organized in Sola without exceeding the 160 A limit.

Table 6: Phase rotation for Sola's chargers.

	PH1	**PH2**	**PH3**
1	L1 - 32 A	L2 - 32 A	L3 - 32 A
2	L2 - 32 A	L3 - 32 A	L1 - 32 A
3	L3 - 32 A	L1 - 32 A	L2 - 32 A
4	L1 - 16 A	L2	L3
5	L2	L3	L1 - 16 A
6	L3	L1 - 16 A	L2
7	L1 - 16 A	L2	L3
8	L2	L3	L1 - 16 A
9	L3	L1 - 16 A	L2
10	L1 - 16 A	L2	L3
11	L2	L3	L1 - 16 A
12	L3	L1 - 16 A	L2
13	L1 - 16 A	L2	L3
14	L2	L3	L1 - 16 A
Total	**160 A**	**144 A**	**160 A**

If the charging is organized this way, the maximum simultaneous charging power becomes:

$$\frac{3 * 160\ A * 230\ V}{1000} = 110,4\ kW \tag{5}$$

In other words, the current limit of 160 A limits the total charging power to 110 kW, but to be on the safe side, in this analysis, the maximum charging power is set at 100 kW. This is the amount of power which can be used every hour for the EV charging, meaning that up to three EVs could be charged with 22 kW three-phase and 11 EVs with 3 kW single-phase simultaneously without exceeding 100 kW. One observation from the Table 6 is that there is only 144 A in phase 2, whereas in phase 1 and phase 3 each carry the maximum current of 160 A. This means that one more single-phase charger of 16 A could be installed to phase 2 without exceeding the current limit of 160 A. However, it would mean that less power would be available for the other chargers, since the number of chargers would increase but the maximum amount of capacity would stay the same.

With the knowledge of the electricity consumption, current limits and behaviour of the EV owners, models of how the EV charging could be organized in Sola can be generated. The modelling is done both for stand-alone charging and smart charging of which stand-alone charging is modelled and analyzed first. As discussed in Section 2.1.1, in stand-alone charging, all EVs receive the same amount of electricity independently from other load's consumption. Figure 10 shows an example of how stand-alone charging could be organized in Sola.

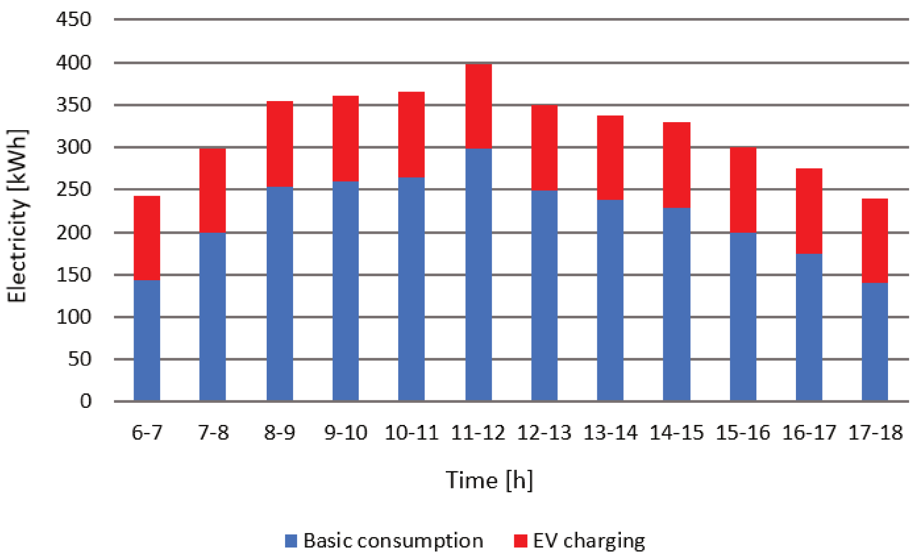


Figure 10: Stand-alone charging in Sola with maximum charging capacity.

In the this option, every hour 100 kWh electricity is available for the EV charging. This means that each EV is charged at 7,1 kW every hour regardless of the consumption of the other loads in the building. Since currently only three of the EVs can be charged in three-phase simultaneously to not exceed the current limit of 160 A, all chargers would need to operate in single-phase. The reason for this is that stand-alone chargers do not communicate with each other and therefore would not know how many EVs are charging in three-phase if any. However, the phase rotation is generally associated with smart charging since it enables to organize the charging in a more efficient and optimal way. Without the phase rotation, the 160 A current limit would only be enough to give 11 A of charging current for the chargers instead of the preferred 16 A. Because of this, the current limit would need to be increased to 224 A, which requires an increase of the fuse size being an expensive investment.

By organizing the stand-alone charging in a way that all EVs receive 16 A and 7,1 kW, in 8 hours, the total charging capacity would become 57,1 kWh per EV, which would give enough of capacity to be able to drive 50 km after the work day. However, during the peak hours, the electricity consumption would be very high and may exceed some capacity limits in Sola's electricity system. By reducing the charging capacity by one third from 100 kW to 67 kW instead, the total electricity consumption during the working hours would become 804 kWh and the consumption during peak hour would be closer to 350 kWh than 400 kWh. In this model, each vehicle would get charged at 4,8 kW every hour and in 8 hours, the total charged energy would be 38 kWh, which is also enough to drive 50 km after the working day being a viable solution. In Figure 11, the updated model for stand-alone charging can be seen.

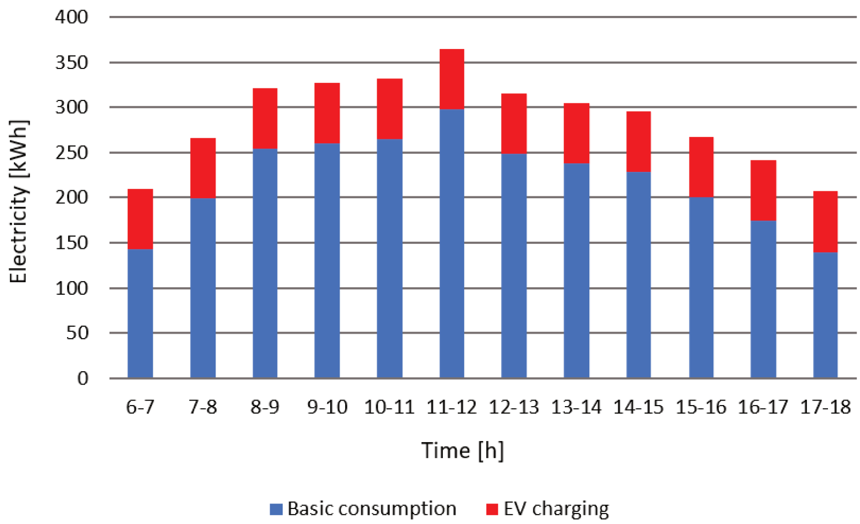


Figure 11: Stand-alone charging in Sola.

The second charging option is smart charging, where the charging power can vary depending on the available capacity and the energy consumption of the other loads. As seen from Figure 9, very few of the EV drivers arrive to work before 7 or leave after 18, which needs to be taken into account in the analysis. According to Figure 9, most of the EV owners arrive around 9 in the morning and leave around 17 in the afternoon. For this reason, this time interval is the most interesting and needs to be kept in focus. The goal is to make sure that those EV owners that arrive around 9 and leave around 17 have enough charging power available. In Figure 12, a model of how Sola's charging could be organized in a smart way can be seen. The total maximum electricity usage is set at 300 kWh to be sure to not exceed any capacity limits in the building. The maximum charging power of 100 kW and the capacity limit of 160 A are also taken into account by utilizing smart chargers load management characteristics and phase rotation. The blue bars show the basic consumption and the red bars the capacity reserved for EV charging.

In this model, 807 kWh (C3) of capacity is reserved for smart charging daily. The

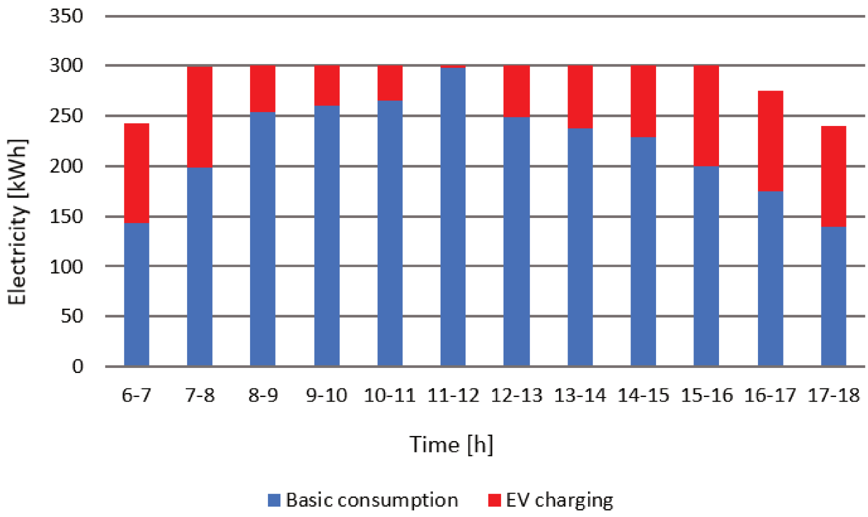


Figure 12: Smart charging in Sola.

capacity is divided between the working hours according to the level of the other loads consumption in the building. In the morning and afternoon when the basic consumption is low, more capacity is reserved for the EV charging. During the day, there is less available electricity, which results in smaller charging powers. Between 11 to 12 when the consumption is the highest, only 2 kWh is available, which is enough power for only one vehicle. For all the other vehicles, the charging is stopped for one hour. The reason for this is that the minimum current to start a charging event in single-phase charging is 8 A, which corresponds to 1,84 kW. For 14 vehicles the minimum power to start the charging events is much higher as seen from (6).

$$14 * 230\ V * 8\ A = 25,7\ kW \tag{6}$$

In Table 7, the total charging powers available for the 14 chargers each hour can be seen. 0 kW is set as charging power from 11 to 12, since only one of the chargers can receive 2 kW of charging power and the other chargers are on stand-by.

From 9 to 17, which is the most interested time interval to study, the total energy charged according to Table 7 is 32,7 kWh. It is enough to charge an EV with a 50 kWh battery from 20% to 80% and it is also more than enough to be able to drive 50 km after the work day making this option viable. These calculations are valid when all of the 14 charging points are in use and the charging power is divided equally between each EV every hour. If fewer than 14 EV are charging, the charging powers will be automatically higher, since there would then be more electricity available for fewer charging points resulting in faster charging times for those EVs that are able to receive higher charging powers.

However, not all employees or possible guests and visitors can charge their EVs 8 hours per day at the office, meaning that they need to get more electricity than

Table 7: Charging powers in Sola.

	Total charging power available [kW]	Power per charging point [kW]
06-07	100	7,1
07-08	100	7,1
08-09	46	3,3
09-10	40	2,9
10-11	35	2,5
11-12	2	0
12-13	51	3,6
13-14	62	4,4
14-15	71	5,1
15-16	100	7,1
16-17	100	7,1
17-18	100	7,1

the others to be able to get the same capacity in a shorter time. That is why the total charging power can not be divided equally between the 14 charging points as shown in Table 7. A more practical and specific model of how the charging could be organized in Sola in a even smarter way can be seen in Table 8. The 3-phase and 1-phase columns with corresponding charging currents show how many EVs would be charged with respective powers each hour.

Table 8: Smart charging in Sola.

	Available power [kW]	3-phase, 16A	1-phase, 32A	1-phase, 16A	Total [kW]
06-07	100	5 * 11 kW	3 * 7,4 kW	6 * 3,7 kW	99,4
07-08	100	5 * 11 kW	3 * 7,4 kW	6 * 3,7 kW	99,4
08-09	46	1 * 11 kW	1 * 7,4 kW	12 * 2,3 kW	46
09-10	40	0	2 * 7,4 kW	12 * 2,1 kW	40
10-11	35	0	2 * 7,4 kW	12 * 1,6 kW	34
11-12	2	0	0	1 * 2,0 kW	2
12-13	51	1 * 11 kW	2 * 7,4 kW	11 * 2,2 kW	50
13-14	62	1 * 11 kW	2 * 7,4 kW	11 * 3,2 kW	61
14-15	71	1 * 11 kW	3 * 7,4 kW	10 * 3,7 kW	70,2
15-16	100	5 * 11 kW	3 * 7,4 kW	6 * 3,7 kW	99,4
16-17	100	5 * 11 kW	3 * 7,4 kW	6 * 3,7 kW	99,4
17-18	100	5 * 11 kW	3 * 7,4 kW	6 * 3,7 kW	99,4

In this model, every EV will receive at least 1,6 kW every hour except between 11 and 12 when there is only 2 kW available for the most recently arrived vehicle. For everyone else, the charging is stopped for one hour. During other times, one to three EVs will be charged at 32 A with a charging power of 7,4 kW. The rest of the EVs will receive either single-phase or three-phase power at 16 A varying from 1,6 kW to 11 kW. Every 15 minutes, the load management system in the chargers would check the situation and possibly change which EVs get to charge at 32 A and which at 16 A. Furthermore, if a vehicle can not receive three-phase power, it will only be charged with single-phase power. However, those employees whose EVs are 8 hours per day at the office do not necessarily need to be charged with three-phase power at all even if they could be. The reason for this is that the average charging power between 9 and 17 is 2,5 kW if charged at 16 A single-phase, which means that the EVs are able to drive 50 km already after 3,5 hours of charging. It could be possible to have user identification in the chargers and define for those users that are 8 hours per day at the office that their EVs only get charged with single-phase power even if their vehicles would be capable of receiving three-phase power. This way, all the EVs that really need higher charging powers, would be able to receive it. However, if for some reason these employees would have a shorter day and would need to receive also higher charging powers, they could identify themselves with a visitors badge for example, which would allow their EVs to receive also three-phase charging.

Furthermore, if needed, during hours from 12 and 15, an alternative charging plan could be used. The alternative charging powers can be seen from Table 9. This option could be used if one or two new EVs would arrive in the middle of the day to the charging points. This enables high charging power for the newest vehicle or vehicles to make sure that they get enough power before the end of the day.

Table 9: Alternative model for smart charging in Sola.

	Available power [kW]	3-phase, 16A	1-phase, 32A	1-phase, 16A	Total [kW]
12-13	51	1 * 11 kW	3 * 7,4 kW	10 * 1,7 kW	50,2
13-14	62	2 * 11 kW	0	12 * 3,3 kW	61,6
14-15	71	2 * 11 kW	1 * 7,4 kW	11 * 3,7 kW	70,1

These charging models assume that the electricity consumption in Sola follows the graph in Figure 8 every day. In reality, the electricity consumption varies daily which have an affection on the charging powers. That is why the load management system in the building needs to communicate continuously with the chargers to adjust the charging powers according to the real electricity consumption. If there would be less electricity available for the charging than calculated, the single-phase charging powers would be slightly reduced or a charger charging in three-phase would drop its charging power. On the other hand, if other loads would consume less electricity, more power could be used for EV charging and the single-phase powers could be higher instead. Through load modelling, an accurate model of Sola's electricity consumption can be made for each day. The load management system would then compare the real consumption with the expected one and adjust the electricity available for the chargers accordingly.

Another way to organize smart charging is to charge according to the spot prices. The idea is to allow charging when the electricity price is below some predetermined value. However, looking at Table 5, it is very difficult to set a price limit on the charging since the prices differs from day to day remarkably and it is not possible to have a situation where the employees EVs do not get charged, because the electricity prices are too high. It is the work places duty to make sure that it offers enough charging power to all of the employees EVs so that they are able to drive safely home after the work day.

Shopping center

The data analyzed in Ideapark's case is electricity data with an hourly resolution from April 2019 and EV charging data from the beginning of July in 2018 to the end of March in 2019. The daily electricity consumption data is generated from the monthly electricity data. The daily electricity consumption with hourly resolution for Ideapark can be seen in Figure 13.

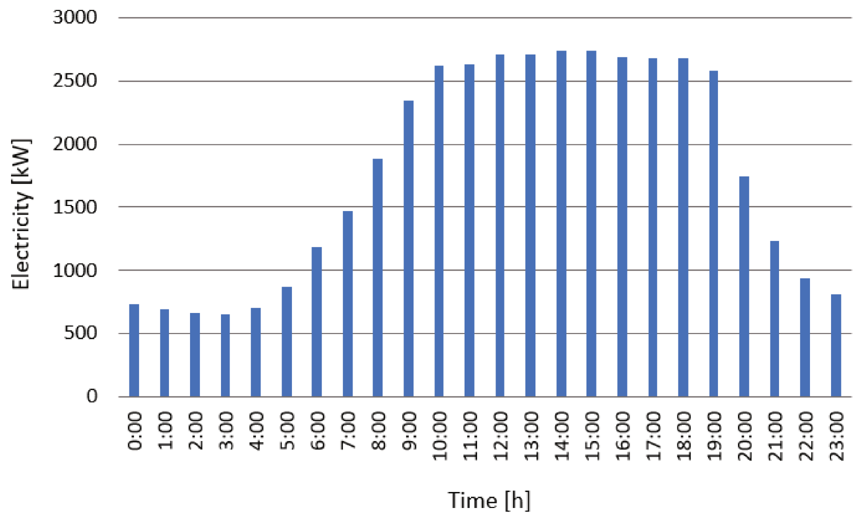


Figure 13: Electricity consumption in Ideapark.

The hourly consumption does not vary much between weekdays and weekends, since Ideapark is open seven days a week. Each day follows very closely the pattern of Figure 13 and that is why for each day, the same model can be used. As seen from the Figure, the consumption varies greatly during the day. Between 22:00 in the evening and 5:00 in the morning, the electricity consumption is at the lowest, being below 1 000 kW each hour. Between 6:00 and 8:00 in the morning and 20:00 and 21:00 in the evening the consumption is between 1 000 kW and 2 000 kW and during 9:00 and 19:00 when Ideapark is open, the consumption is constantly over 2 000 kW.

When it comes to EV charging, from the beginning of August 2018 to the end of March 2019, 4 320 charging events have taken place in Ideapark. The average charging time has been close to 2 hours and the average energy consumed 7,2 kWh per charging event. Furthermore, the busiest charging day has been Saturday by far. During the 9 months period, on Saturdays, over 1 000 charging events have taken place when the respective number for the other days is between 400 and 600 events. On average, 20 charging events have occurred daily in Ideapark, but in January 5th, 2019, over 100 charging events took place. During that day, over 30 of the chargers were used simultaneously meaning that currently the 40 charger points are enough to meet the demand. However, if the number of EVs continues to increase as before, all 40 charging points will be in use after couple of years, which requires acquisition of new charging points. All the 4 320 charging events according to their start and stop times can be seen in Figure 14.

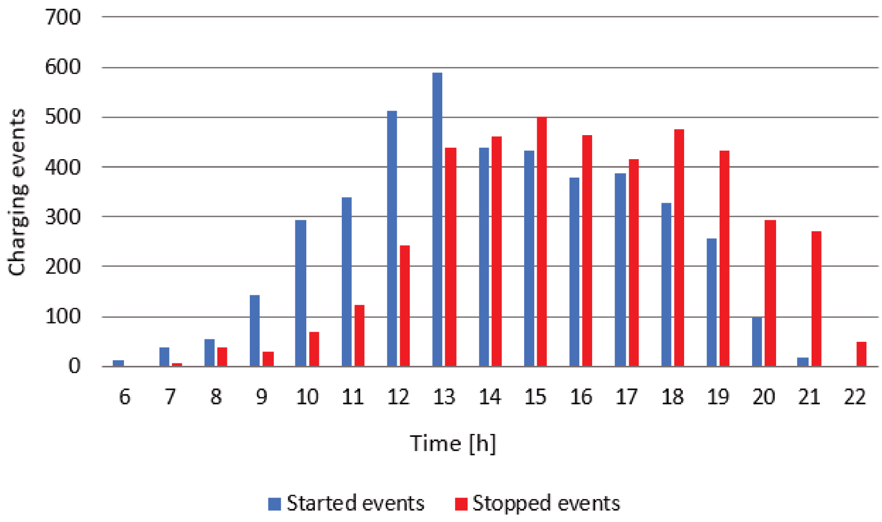


Figure 14: Charging events in Ideapark.

As seen from Figure 14, most of the EVs arrive around midday and leave after a few hours. However, there are vehicles charging all the way from 6:00 in the morning to 22:00 at the evening. The goal is to arrange the EV charging in a way that when the customers have charged for 2 hours, the EVs would have gotten enough of electricity to drive up to 70 km, which is about the distance between Hämeenlinna and Ideapark. This way the customers with EVs can visit Ideapark both from Tampere, which is located closer to Ideapark, as well as from Hämeenlinna, without having the need to worry if they have enough electricity to drive back home. If using the same values to calculate the charging times as in Sola's case, it takes only 34 minutes to be able to drive 70 km if charged with 22 kW, as seen from (7). Similarly, if charged with 7,4 kW, the charging time would be 1 hour 42 minutes, which would still be acceptable.

$$\frac{0,18\ kW/km * 70\ km}{22\ kW/h} = 0,57\ h = 34\ min \tag{7}$$

Also in Ideapark's case, the current limit must be taken into account, meaning that no more than 400 A can be used for EV charging. Without phase rotation and all chargers in use, only 10 A would be available for each EV. This corresponds to only 2,3 kW of charging power as seen from Table 1, which would not be sufficient. However, by utilizing phase rotation, up to 7 EVs could be charged with 32 A and the rest with 16 A simultaneously. In Table 10 the phase rotation for Ideapark's chargers is illustrated.

Table 10: Phase rotation for Ideapark's chargers.

	PH1	**PH2**	**PH3**
1	L1 - 32 A	L2 - 32 A	L3 - 32 A
2	L2 - 32 A	L3 - 32 A	L1 - 32 A
3	L3 - 32 A	L1 - 32 A	L2 - 32 A
4	L1 - 32 A	L2 - 32 A	L3 - 32 A
5	L2 - 32 A	L3 - 32 A	L1 - 32 A
6	L3 - 32 A	L1 - 32 A	L2 - 32 A
7	L1 - 32 A	L2 - 32 A	L3 - 32 A
8	L2	L3	L1 - 16 A
9	L3	L1 - 16 A	L2
10	L1 - 16 A	L2	L3
11	L2	L3	L1 - 16 A
12	L3	L1 - 16 A	L2
13	L1 - 16 A	L2	L3
14	L2	L3	L1 - 16 A
15	L3	L1 - 16 A	L2
16	L1 - 16 A	L2	L3
17	L2	L3	L1 - 16 A
18	L3	L1 - 16 A	L2
19	L1 - 16 A	L2	L3
20	L2	L3	L1 - 16 A
21	L3	L1 - 16 A	L2
...	...	...	...
37	L1 - 16 A	L2	L3
38	L2	L3	L1 - 16 A
39	L3	L1 - 16 A	L2
40	L1 - 16 A	L2	L3
Total	**400 A**	**400 A**	**400 A**

By organizing the charging in accordance to Table 10, each of the three phases conduct 400 A of current, resulting in an evenly balanced electrical system. The maximum simultaneous charging power becomes:

$$\frac{3 * 400\ A * 230\ V}{1000} = 276\ kW \tag{8}$$

In other words, 276 kW is the maximum simultaneous charging power that can be used for EV charging but, to be on the safe side, 270 kW is used as the maximum power for the modelling of the EV charging in Ideapark.

By applying the knowledge of the electricity consumption, current limits and behaviour of the EV owners, models of how the EV charging could be organized in Ideapark can be generated. The modelling is done both for stand-alone charging and smart charging, of which stand-alone charging is modelled first. In stand-alone charging, the maximum power of 270 kW is divided equally between the 40 charging points, meaning that 6,75 kW of charging power is available for all EVs. A model of stand-alone charging can be seen in Figure 15. Only hours from 9:00 to 21:00 are analyzed since during those hours Ideapark is open and most of the charging events takes place as seen from Figure 14. In stand-alone charging, the grouping of the chargers does not have an affect on the charging powers since the powers remain constant independent from the number of EVs charging. With 6,75 kW available for each charger, the total power of a group of 10 chargers, will be 67,5 kW. This is acceptable since the 160 A charging current limit per group enables a total charging power of 110 kW, which means that no capacity limits are being exceeded.

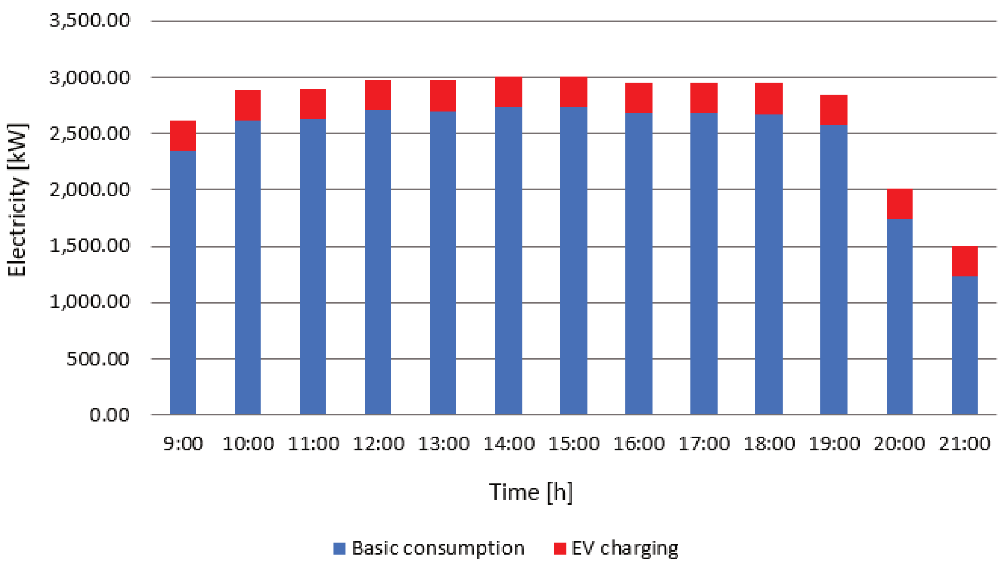


Figure 15: Stand-alone charging in Ideapark.

The charging power of 6,75 kW would be enough in a situation where all EV owners would stay in Ideapark for 2 hours. However, this is not the case since some of the customers have only charged for 20 minutes when others have been charging over 9 hours. Similar to Sola's case, since the stand-alone chargers do not communicate with each other, all the charging would need to be in single-phase in order to not exceed the current limit of 400 A, meaning that also three-phase vehicles receive only single-phase power. Furthermore, since phase rotation is associated with smart charging instead of stand-alone charging, the total current limit of 400 A is not enough to provide the needed 16 A of current for each of the 40 charging points.

Instead, the 160 A maximum current limit of each group would be need to be used to be able to provide 16 A per charger. Due to this, the total current limit would need to be increased to 640 A, requiring reinforcements in the electrical system.

Finally, if 270 kW is always used for the EV charging, during some hours, the total electricity consumption in Ideapark will increase above 3 000 kW. As seen from Figure 15, during the hours of 14:00 and 15:00, the total electricity consumption is 3 012 kW and 3 006 kW respectively. Although the overloading is modest in this case, some capacity limits may still be exceeded in the electricity system.

In smart charging on the other hand, the power can be distributed variously between the 40 charging points. For EVs that can only charge in single-phase, the minimum charging power to be able to charge 70 km in 2 hours is 6,3 kW, assuming that the customers arrive with an almost empty battery. This is the charging capacity that all single-phase EVs have to receive in 2 hours.

The phase rotation can also be done in a different way than in Table 10. Up to 3 vehicles can be charged with 32 A 3-phase, 5 EVs with 16 A 3-phase, 9 EVs with 32 A in single-phase and the rest of vehicles with 16 A in single-phase. However, the power restriction of 270 kW has to be taken into account. It enables 3 EVs to be charged with 22 kW, 5 EVs with 11 kW, 8 EVs with 7,4 kW and the rest 24 EVs with 3,7 kW, resulting in a total charging power of 269 kW for each hour as seen from Table 11. The load management system will then change the current values between 16 A and 32 A for both single-phase and three-phase vehicles every 15 minutes, to ensure that all EVs receive enough electricity. This model assumes that all 40 charging points are in use at the same time.

Table 11: Smart charging in Ideapark.

	3-phase, 32A	3-phase, 16A	1-phase, 32A	1-phase, 16A	Total [kW]
09-10	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
10-11	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
11-12	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
12-13	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
13-14	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
14-15	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
15-16	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
16-17	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
17-18	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
18-19	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
19-20	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269
20-21	3 * 22 kW	5 * 11 kW	8 * 7,4 kW	24 * 3,7 kW	269

If focusing on single-phase charging and its organizing in Ideapark, a more detailed model of how the single-phase charging together with a load management system could be implemented can be seen in Figure 16. The load management system changes every 15 minutes, determining which EVs receive 7,4 kWh and which 3,7 kWh. In one hour, all 32 single-phase charging points, would have been able to charge in both 16 A and 32 A, giving 4,6 kWh of energy to all 32 vehicles.

	0-15 min	15-30 min	30-45 min	45-60 min
1	7,4	3,7	3,7	3,7
2	7,4	3,7	3,7	3,7
3	7,4	3,7	3,7	3,7
4	7,4	3,7	3,7	3,7
5	7,4	3,7	3,7	3,7
6	7,4	3,7	3,7	3,7
7	7,4	3,7	3,7	3,7
8	7,4	3,7	3,7	3,7
9	3,7	7,4	3,7	3,7
10	3,7	7,4	3,7	3,7
11	3,7	7,4	3,7	3,7
12	3,7	7,4	3,7	3,7
13	3,7	7,4	3,7	3,7
14	3,7	7,4	3,7	3,7
15	3,7	7,4	3,7	3,7
16	3,7	7,4	3,7	3,7
17	3,7	3,7	7,4	3,7
18	3,7	3,7	7,4	3,7
19	3,7	3,7	7,4	3,7
20	3,7	3,7	7,4	3,7
21	3,7	3,7	7,4	3,7
22	3,7	3,7	7,4	3,7
23	3,7	3,7	7,4	3,7
24	3,7	3,7	7,4	3,7
25	3,7	3,7	3,7	7,4
26	3,7	3,7	3,7	7,4
27	3,7	3,7	3,7	7,4
28	3,7	3,7	3,7	7,4
29	3,7	3,7	3,7	7,4
30	3,7	3,7	3,7	7,4
31	3,7	3,7	3,7	7,4
32	3,7	3,7	3,7	7,4

Figure 16: Single-phase charging in Ideapark.

If the single-phase charging is organized as seen in Figure 16, in 75 minutes, 8 of the EVs would have received 6,5 kW, which is enough to drive 70 km, and 24 of the EVs 5,6 kW as seen from (9).

$$\frac{(2*7,4+3*3,7)\ kW}{4} = 6,5\ \ kW, \quad \frac{(1*7,4+4*3,7)\ kW}{4} = 5,6\ \ kW \quad (9)$$

Furthermore, after 90 minutes, all EVs would have received either 6,5 kW or 7,4 kW of power. As seen from the calculated powers, those EVs, which can only charge in single-phase, would receive enough electricity in under 2 hours. The three-phase charging for the 8 remaining chargers would be organized in a similar way having 3 of the EVs charging at 22 kW and 5 EVs at 11 kW with the LMS changing the powers every 15 minutes. Those EVs that are able to charge in three-phase, will have received enough electricity in 30 to 45 minutes depending on if charged with 11 kW or 22 kW. As stated before, this model assumes that all 40 charging points are in use. If less than 40 EVs are charging, the charging powers could be even higher for those who would receive single-phase power, which would result in even shorter charging times for those EVs.

However, during some hours when the basic consumption is higher than usually and if 270 kWh of electricity is used for the EV charging, the 3 000 kWh limit may be exceeded. Fortunately, together with smart charging and Ideapark's LMS, the capacity limit can be set at 3 000 kWh ensuring that no capacity limits in the buildings electricity system are exceeded. One example of an alternative charging model can be seen in Table 12, when less than 270 kWh of electricity is available for the charging. The data used in this example is from Saturday 20.4.2019 between 13:00 and 17:00.

Table 12: Alternative model for smart charging in Ideapark.

	Available power [kW]	3-phase, 32A	3-phase, 16A	1-phase, 32A	1-phase, 16A
13-14	212	0	4 * 11 kW	9 * 7,4 kW	27 * 3,7 kW
14-15	198	0	4 * 11 kW	5 * 7,4 kW	31 * 3,7 kW
15-16	201	0	4 * 11 kW	6 * 7,4 kW	30 * 3,7 kW
16-17	258	2 * 22 kW	6 * 11 kW	8 * 7,4 kW	24 * 3,7 kW

The downside of this practice is that during hours when the basic consumption is higher and less than 270 kW is available for the charging, the EVs will get slightly less charging powers, which increases the charging times. If the basic consumption continues to restrict the charging capacity to an increasing extent, it may be worth thinking about increasing the 3 000 kWh limit for example to 3 500 kWh. This may however need reinforcements of the electricity system, which is expensive.

This model of smart charging was created by the assumption that all 40 charging points are in use simultaneously. However, the situation changes when fewer EVs are charging because of the clustering of the chargers. As stated before, each group has 160 A available resulting in a group-specific charging power of 110 kW. If all chargers in one group are in use and assuming that the three other groups are unoccupied, each EV would be able to receive 11 kW at 16 A being enough to drive 70 km after 2 hours of charging. If respectively only 5 EVs would be charging in one group, the charging powers for the EVs could be up to 22 kW at 32 A.

Of total 4 clusters, chargers of two and a half groups could be used at the same time to not exceed the total system limit of 400 A. This would mean that 25 EVs could be charged with 11 kW at 16 A simultaneously. If there would be vehicles that could only receive 3,7 kW or 7,4 kW, more charging power would be available for the other vehicles in the same group as long as the group-specific limits of 160 A and 110 kW do not exceed. If more than 25 EVs are charging, the LMS is needed to adjust the charging powers according to the Table 11 but as long as 25 EV or less are charging, the charging power for all the EVs can be up to 11 kW at 16 A.

4.2 Economic analysis

In this section, the economic analysis is conducted. For both buildings, first the basic electricity cost without EV charging is calculated with two different tariffs. After this, the electricity costs for stand-alone charging and smart charging are calculated with the same tariffs. At the end, the obtained results are compared with each other to find out which one of the two ways of charging is cheaper and which tariff suits best to be used in commercial buildings with integrated EV charging.

Office building
In Sola, the yearly energy consumption as stated earlier is around 1,31 GWh, which corresponds to 1 310 000 kWh. The general energy price calculated previously is 6,34572 c/kWh including the taxes. The cost for Sola's yearly energy consumption becomes:

$$1\ 310\ 000\ kWh * 6,34572\ c/kWh = 8\ 312\ 893,2\ c = 83\ 128,9\ € \tag{10}$$

When adding the transmission cost to the energy price, which is 3,14 c/kWh and the monthly fixed fee of 5,90 €, the total yearly cost for Sola's electricity consumption becomes:

$$83\ 128,9\ € + \frac{1\ 310\ 000\ kWh * 3,14\ c/kWh}{100} + 12 * 5,90\ € = 124\ 333,7\ € \tag{11}$$

Almost 125 thousand euros is used yearly to pay Sola's electricity consumption if calculated with the general tariff. In these calculations the electricity used for EV charging is not included meaning that it needs to be added to the cost.

When looking only at the workdays, the total sum of the electricity consumption used by the basic loads between 6:00 and 18:00 is 2 650 kWh (C1). If calculating the cost for the electricity consumption during workdays with the general tariff, the cost per day for the working hours is:

$$2\ 650\ kWh * 6,34572\ c/kWh = 16\ 816,16\ c = 168,16\ € \tag{12}$$

The electricity usage costs slightly less than 170 € per working day in Sola when calculated with the general tariff. However, if calculating the electricity consumption for each work day with the different spot prices, the cost varies significantly. When looking at the spot prices from Table 5, it is possible to see that in January 2018, the prices were fairly low. When calculating the daily cost with the spot prices from January 14 2018, the price for the energy including the taxes becomes 153,72 € (C12), which is around 15 € cheaper than if calculated with the general tariff. However, around one year later the spot prices has increased significantly from what they were in 2018. Calculating with the spot prices from 18th January 2019, the price for the energy becomes 221,98 € (C21), being almost 54 € more expensive. Furthermore, couple of days later, on January 24 2019, the spot prices for the energy were extremely high. With these prices the electricity bill would be as high as 330,19 € (C30), which is over two times higher than with the lowest spot prices. In February, the energy prices were again lower, which results in a more acceptable energy bill of 195,47 € (C39). The calculations for each energy cost can be seen in Appendix C.

On top of the basic electricity consumption, the electricity used for EV charging needs to be added. In stand-alone charging, every hour 67 kW is available to be used for EV charging. This means that for each of the 14 charging points, 4,8 kWh of energy is available. With the general tariff, the cost for the electricity that can be used for charging between 6:00 and 18:00 is:

$$12\ h * 67\ kW * 6,34572\ c/kWh = 5\ 102\ c = 51,02\ € \tag{13}$$

By adding the cost for EV charging to the basic energy cost of 168,16 €, the energy cost for the working hours increases to over 200 € per day. The EV charging increases the daily electricity cost with 30%, which is significant. In a year, if calculating with 260 days by taking only weekdays into account, the total yearly electricity cost including the electricity used for EV charging becomes:

$$124\ 333,7\ € + 260 * 51,02\ € = 137\ 598,9\ € \tag{14}$$

In total, stand-alone EV charging increases Sola's electricity bill with over 13 200 € per year corresponding to a 10% increase.

If calculating the cost for the electricity used for stand-alone EV charging with the spot prices instead, the cost varies significantly. Since during January 14, 2018, the electricity prices where low, the cost for EV charging would be 46,77 € (C15) per day, which is little under 5 € cheaper than with the general tariff. However, in January

18 2019, the prices where higher resulting in a cost of 67,46 € (C24) for the charging. With electricity prices from 24th January 2019, the cost for EV charging becomes 99,57 € (C33). Finally, with the prices from 18th February 2019 the cost for the charging becomes 59,42 € (C42). At least in stand-alone charging, it seems to be cheaper to charge with the general tariff since the electricity used for EV charging is the same every hour and during 2019, the general tariff has been cheaper than the spot prices.

In smart charging, the electricity used for the EV charging can vary during the day. In total, 800,2 kWh (C4) of electricity is used daily for the charging on average. With the general tariff the cost for the electricity becomes:

$$800,2\ kWh * 6,34572\ c/kWh = 5\ 077,85\ c = 50,78\ € \tag{15}$$

It is slightly less than in stand-alone charging since in smart charging the consumption is 4 kWh less per day. In a year, when calculating with 260 days, the cost for the smart charging would become 13 202 €, being over 60 € cheaper than with stand-alone charging.

If calculating the cost with the different spot prices, the costs varies all the way from 46,77 € (C15) to 97,62 € (C36), which are slightly less when compared with the stand-alone charging. The differences in the energy prices between stand-alone charging and smart charging when calculated with the spot prices can be seen in Table 13.

Table 13: Differences in Sola's daily energy prices.

Dates	Stand-alone [€]	Smart [€]	Difference [€]
14.01.2018	46,77	46,77	0
18.01.2019	67,46	67,36	0,10
24.01.2019	99,57	97,61	1,94
18.02.2019	59,42	59,33	0,09

Also in smart charging, the cost for the electricity becomes more expensive with spot prices than with the general tariff except if calculating with the spot prices from January 2018. The reason for this is that the spot prices have been very high recently which affects the cost directly. Since the employees and possible visitors EVs need to be charged during the day no matter of the electricity price, general tariff seems like a more profitable option. It is also easier to plan the budget and expenses for a year with a fixed electricity cost. Furthermore, with general tariff it is possible to avoid surprises regarding the electricity cost as the extremely high prices during 24th January 2019.

Shopping center

In Ideapark, the yearly energy consumption as stated earlier is around 14,8 GWh, which corresponds to 14 800 000 kWh. The general energy price calculated previously is 6,34572 c/kWh including the taxes. The cost for the yearly energy consumption in Ideapark becomes:

$$14\ 800\ 000\ kWh * 6,34572\ c/kWh = 93\ 916\ 656\ c = 939\ 166,6\ € \tag{16}$$

Almost 1 million euros is used yearly to pay Ideapark's electricity consumption. When it comes to the daily electricity usage, the daily average consumption in Ideapark is around 41 000 kWh. However, since most of the EV charging occurs between 9:00 and 21:00, only this time interval is relevant and studied here. During the weekdays and on Saturday, on average 30 800 kWh of electricity is used between 9:00 and 21:00, when on Sundays, only around 24 000 kWh of electricity is used. Since during most of the days the 30 800 kWh is the average consumption, it is used in the analysis. The cost for the electricity per day with the average consumption of 30 800 kWh is:

$$30\ 800\ kWh * 6,34572\ c/kWh = 195\ 448,18\ c = 1\ 954,48\ € \tag{17}$$

Ideapark's daily electricity consumption costs slightly less than 2 000 € when calculated with the general tariff. With the spot prices, the cost varies significantly. With the spot prices from 14th January 2018, the price including taxes is 1 181,19 € (D8), being over 770 € cheaper than with the general tariff. However, during 2019 with higher spot prices, the cost varies from 2 271,22 € (D35) up to 3 722,98 € (D26), which are clearly higher than with the general tariff. The calculations for each energy cost can be seen in Appendix D.

On top of the basic consumption, the cost of EV charging needs to be added. With stand-alone charging, every hour, 270 kWh is reserved for the charging resulting in a total consumption of 3 240 kWh (D1) per day. This means that all EVs get 6,75 kW charging power every hour, which is enough if charged for 2 hours. Furthermore, with stand-alone charging and no load management system, the consumption would during some days exceed 3 000 kW on the peak hours, which may exceed some capacity limits in Ideapark's electrical system. With the general tariff, the cost for stand-alone charging per day becomes:

$$3\ 240\ kWh * 6,34572\ c/kWh = 20\ 560,13\ c = 205,60\ € \tag{18}$$

By adding the cost for stand-alone EV charging to the basic electricity cost, the total cost per day would become 2 160,08 € with the general tariff. The cost for EV charging increases the total electricity cost with little over 10% per day. In a year, if calculating with 360 days, excluding few holidays when Ideapark is closed, the total yearly electricity cost including the electricity used for stand-alone EV charging becomes:

$$939\ 166,6 \text{ €} + 360 * 205,60 \text{ €} = 1\ 013\ 182,6 \text{ €} \tag{19}$$

In total, stand-alone EV charging increases Ideapark's yearly electricity bill with around 74 000 €, corresponding to a increase of 7%.

If calculating the cost for stand-alone charging with the spot-prices, there is again a large variation in the cost. With the electricity prices from 14th January 2018, the cost for stand-alone charging becomes 190,81 € (D11), being 14 € cheaper, and together with the electricity cost of 1 181,19 €, the difference is 788 €. However, with the other days spot prices, the cost for stand-alone charging varies between 238,43 € (D38) to 388,27 € (D29) being more expensive than with the general tariff. Also in Ideapark's case, it seems that it is cheaper to charge with the general tariff than with the spot-prices.

What comes to the smart charging, also 270 kW is reserved but only 269 kW of power is used at maximum every hour, resulting in a total consumption of 2 338 kWh (D2). The electricity cost for smart charging with the general tariff becomes:

$$3\ 228\ kWh * 6,34572\ c/kWh = 20\ 483,98\ c = 204,84 \text{ €} \tag{20}$$

The cost is slightly less than compared with stand-alone charging, since the daily consumption is 12 kWh smaller. The daily difference is 0,76 €, resulting in a yearly difference of 274 €.

If calculating the electricity cost for smart charging with the spot prices, the results are very similar to the results for stand-alone charging. Prices from January 24th 2018, results in the cheapest electricity bill of 190,11 € (D14), whereas with the prices from 2019, the cost varies from 271,87 € (D23) to 386,83 € (D32). In the Table 14, the differences between the daily energy costs when calculated with the spot prices for both stand-alone and smart charging can be seen.

Table 14: Differences in Ideapark's daily energy prices.

Dates	Stand-alone [€]	Smart [€]	Difference [€]
14.01.2018	190,82	190,11	0,71
18.01.2019	272,89	271,87	1,02
24.01.2019	388,27	386,83	1,44
18.02.2019	238,44	237,55	0,89

As seen from Table 14, the electricity cost for smart charging is slightly cheaper than with the stand-alone charging. The reason for this is that 269 kWh of energy is used in smart charging every hour, whereas in stand-alone charging, all 270 kWh of energy is used.

4.3 Implementation of the technical requirements

The technical requirements discussed in Section 2.4 are analyzed in this part. How the requirements are taken into account and implemented in each case is studied separately for both buildings.

Office building

The BMS in Sola is the PME fulfilling the definition of a smart building. As chargers, the EVlink Smart Wallbox charging points are used. They have the ability to be connected to a cloud based back-end system and they are capable of all the load management functions i.e. deferred start, charging current limitation and load shedding. One of the 14 EVlink Smart Wallbox chargers located in Sola can be seen in Figure 17.

Figure 17: EVlink Smart Wallbox charger in Sola.

The cloud based back-end system used in Sola is Plugit's own cloud called Pharus Cloud. The user identification and different features including payment options are integrated to the chargers through the back-end system. The connection between the charging stations and the Pharus Cloud is made wirelessly by using WiFi. With regard to the standards, the minimum IK classification level for semi-public charging is IK08 and the IP classification level IP41 if the chargers are located inside a building as in Sola's case. The corresponding classifications for the EVlink Smart Wallbox charging points are IK10 and IP55, which fulfill these requirements.

The charging points are mounted on the wall inside Sola's parking hall, as seen from Figure 17. Another option would have been to have them standing on the ground, but to save space, it was more convenient to install them on the wall. All the chargers are connected through Canalis to the electrical supply. The choice to use Canalis instead of traditional cabling was both an economic as well as a practical decision. Firstly, since the EV charging stations are inside Sola's parking hall, it was possible to use the Canalis. Secondly, the Canalis is associated with a smart system, which Sola's EV charging system is. Finally, with over 5 charging stations, the Canalis was also the cheaper option and faster to install, which saved both time and money.

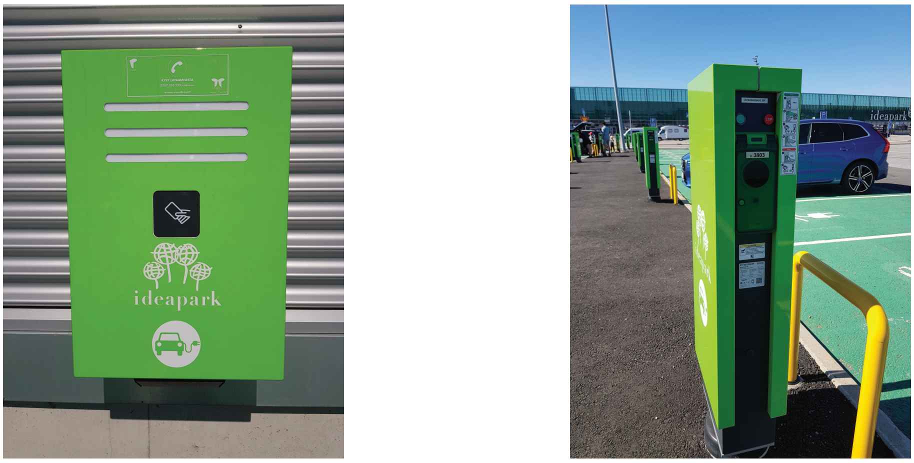
The electricity for the chargers is taken from the NK distribution board instead of one of the main switchboards. The reason for wanting to use the NK initially was because it is located closer to the charging points and only one short cable would be needed to connect the Canalis and the chargers to the electrical supply. However, it was not certain if the NK would have enough capacity left for supplying the 14 charging stations. Therefore it was important to study how much power the existing loads consume to find out if there would be enough capacity left for the chargers. Several years consumption data collected from the PME was analyzed to find out the peak consumption of the loads to determine whether or not the NK would be suitable to be used as the power source. After studying the energy consumed by the other loads, the conclusion was that there was enough power available for the 14 charging points, if the total charging current was limited to 160 A.

As protection, Compact NSX circuit breakers are used to protect the EV charging installation from fault currents. The CBs have a breaking capacity of 40 A, which provides an adequate overcurrent protection without inadvertently tripping the charging current of 32 A. A Type B RCD is used to protect the employees or visitors against direct or indirect contact with the current. The reason to use a Type B RCD instead of Type A in the chargers is that the Type B is enabled to detect both AC and DC residual fault currents, meaning that no RDC-DD is needed. The Type B is also less sensitive than the Type A RDC-DD combination, which results in fewer complications and disturbances related to the charging. Finally, since the charging is currently organized as a service for the employees and customers, no energy meters are needed, nor are being installed next to the chargers.

Shopping center

Ideapark has a technical facility management system implemented, which takes care of the load management in the shopping center. As chargers, the EVlink Parking charging points are used, which are capable of all the load management functions i.e. deferred start, charging current limitation and load shedding. The chargers are connected to the Plugit's own cloud, identical to Sola's case. The connection from the chargers is made with a fixed network cable, which connects all the 40 charging points to one modem. The connection is made by drawing one cable from each of the charging points to the modem. This practice secures that even if one charging point breaks down and loses its connection, the other charging points are not affected. Another option would have been to connect the charging points in a ring formation. Similarly, if one charging point loses its connection, it does not affect the other chargers functionality but if another charger would break down too, in the worst case all of the connections could be lost depending on the locations of the faulty chargers. From the modem, the connection to the cloud is made with 4G using a VPN (Virtual Private Network) as an intermediary between the modem and the cloud.

The chargers in Ideapark are located outdoors and are in public use, requiring the highest IK classification level of IK10 and the minimum IP classification level of IP44. For EVlink Parking, the corresponding values are IK10 and IP52, which fulfills the requirements. Furthermore, there are two different models of the chargers available depending on the installation method. The chargers can either be installed on the ground or be mounted on the wall. Both of these models are used in Ideapark which can be seen in Figure 18. Two of the 20 chargers are mounted on the wall of the substation and the rest of the chargers are standing on the ground.



(a) EVlink Parking on the wall. (b) EVlink Parking on the ground.

Figure 18: EVlink Parking chargers in Ideapark.

Furthermore, since the chargers are located outdoors, the Canalis could not be used to connect the chargers to the electrical supply. Instead, traditional cabling had to be drawn from the electrical supply, becoming much more expensive than the Canalis would have been.

As protection, 40 circuit breakers are used to protect the whole EV charging installation from fault currents. Similarly to Sola's case, 40 A CBs are used, which provide adequate overcurrent protection regarding the charging current of 32 A, without unintentionally tripping it. Having CBs with a larger breaking capacity would be oversizing and more expensive. As RCDs, the Type B is used instead of the Type A. The reason for this is as stated before, the Type B is enable to detect both AC and

DC residual fault currents, meaning that no RDC-DD is needed. The Type B is also less sensitive resulting in less complications and disturbances related to the charging. This is especially important when dealing with customers who expect functioning chargers and a flawless charging experience. The 40 CBs and RCDs are located inside a distribution board located next to the substation. The protection devices are grouped in four cabinets with 10 protection devices of each type next to each other. One of the four cabinets can be seen in Figure 19. Finally, since the charging is free of charge for the customers, no MID certified energy meters are installed next to the chargers.

Figure 19: One of the four cabinets with 10 CBs and 10 RCDs inside.

4.4 Technical benefits

In this section the technical benefits of having a smart system instead of a stand-alone one are studied. The technical benefits are studied separately for both cases, since the benefits differs from each other depending on the building type and its EV charging system.

Office building

The biggest technical benefit in Sola by having the smart building management system in the building is that the NK distribution board could be used as the electrical supply for the chargers. Without the PME and access to Sola's detailed energy consumption, one of the main switchboards would have been used instead as the electrical supply, since having no access to NK's consumption data, the risk of exceeding the capacity limits of the NK would have been too high. However, after analyzing the energy consumption of the NK's loads, it was clear that there was enough capacity available for the 14 chargers. Having the NK as the electrical supply, a significantly shorter cable could be used to connect the NK to the Canalis, which saved money. Another option would have been to build a dedicated electrical distribution board to supply the chargers only. However, this would have been a costly option of several thousand euros. The final option would have been to use the NK nonetheless but having continuous monitoring of the electricity consumption and adjusting the available current for the chargers dynamically according to the other loads' consumption. However, this option would also have been more costly than having a fixed value for the current, as is the situation at the moment.

Another technical benefit achieved with the smart system was that the size of the main fuse could be kept the same. With the smart load management system in the chargers, the existing 160 A limit is more than enough to be divided between the 14 chargers together with phase rotation and phase balancing. However, in the case of stand-alone charging, the situation is different. Without phase rotation, the 160 A current limit would not have been enough to provide all 14 chargers with 16 A of charging current as needed. Due to this, the limit would needed to have been increased to 224 A, increasing also the fuse size.

Furthermore, the thickness of the cables could be optimized by having a fixed current limit of 160 A. An MCMK copper cable with a cross section of 4*70+35 mm^2 is used, which is the thinnest cable that can handle a constant load of 160 A. By optimizing the cable thickness, both space and money was saved.

All the chargers are equipped with one CB and one RCD. Usually, all the safety equipment should be located inside the electric center. In Sola's case, it would have required an expansion of the NK distribution board to be able to fit all the protection devices inside it. However, the Canalis enabled that no expansion was needed, since the safety equipment is located in the Canalis itself above each charger, requiring no additional space in the distribution board. A CB and a Type B RCD inside the Canalis feed unit for one of the chargers can be seen in Figure 20. Furthermore, the Canalis enables also scalability. As long as Sola's current and capacity limits are taken into account, the EV charging system can easily be expanded by adding new Canalis feed units next to the existing ones to which the new EV chargers are connected.

Due to the back-end system, the chargers can be monitored and controlled continuously. The monitoring enables visibility of the chargers utilization rate, which allows to realize when new EV chargers are needed to be installed to Sola. The back-end system enables also fault management remotely if an error would occur regarding the charging. Finally, due to the intelligence in the chargers and the back-end system, the chargers are customized with different types of payment options according to the wishes of the companies that uses them.

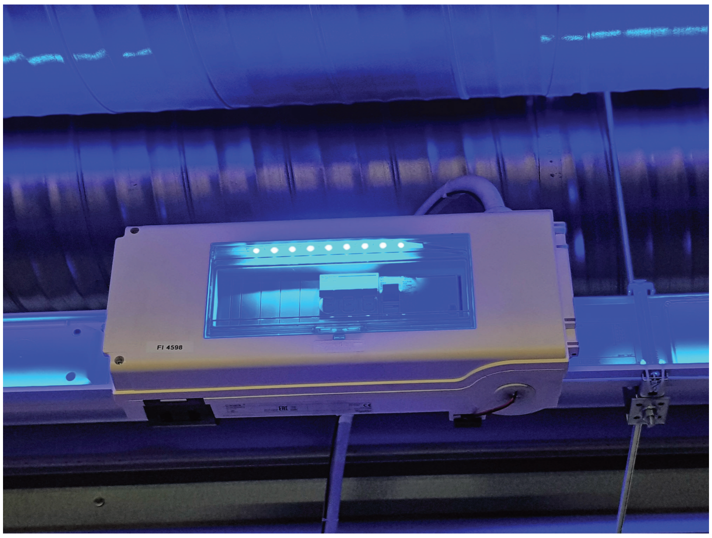


Figure 20: Canalis feed unit with a CB and an RCD inside.

Shopping center

The biggest benefit in Ideapark from having smart chargers that are capable of load management is that the 400 A, which is the maximum current available for the chargers, is sufficient to provide enough power for all EVs to be charged in under 2 hours. Without the smart system and its possibility for load management, the 400 A limit would be needed to be increased to 640 A, meaning that the existing substation would not have sufficed. A new and bigger substation would have been required, entailing a large investment. The smart system also enables higher charging powers if fewer than 40 EVs are charging, which the stand-alone system is not capable of. However, with the smart system the group limitations of 160 A has to be taken into account, which may restrict the charging powers and charging currents available for the EVs.

Furthermore, the smart chargers are able to gather information about the charging events and store up to 30 events or CDRs (Charge Detail Records). This is important if the connection to the cloud would be lost for some reason meaning that the data could not be transferred between the chargers and the cloud. Due to CDR and the local modem to which all the chargers are connected to, even if the connection would be lost to the cloud, the EV charging can continue uninterrupted. The reason for this is that the chargers together with the modem enables load management locally as long as the chargers have memory left. Since the stand-alone chargers are not connected to the cloud, this issue is not relevant for these chargers. However, the stand-alone chargers are not capable of storing charging events, which means that if a fault or issue would occur in the chargers, the charging would be interrupted for the EVs that was charging but also no new EVs could start their charging until the problem would be fixed for the chargers in question. This could have a major negative impact on customer satisfaction and Ideapark's reputation.

Due to the cloud based back-end system provided by Plugit, the chargers can be monitored and controlled remotely. If an error regarding the EV charging would occur, the customer can contact Plugit, who can see the situation remotely from the back-end system and instruct the customer how to resolve the issue. This saves the customer's time since he or she does not have to figure out the problem alone or possibly drive to another charger to charge. Finally, as in Sola's case, the monitoring enables visibility of the chargers utilization rate, which allows to realize when new EV chargers are needed to be installed to Ideapark.

4.5 Economic benefits

In this section, the economic benefits of having a smart system instead of a stand-alone one are studied. The two charging models for both buildings created in Section 4.1 are compared with each other to find out if smart charging is financially more beneficial than stand-alone charging when taken also the investment and installation costs into account. The comparison is done separately for each case since the economic benefits varies depending on the building and their EV charging system.

Office building

In Sola, for both stand-alone charging and smart charging, around 800 kWh of electricity is available during work hours daily. Stand-alone charging enables charging power of 4,8 kW every hour for all of the 14 charging points. However, all the charging would need to be in single-phase and new EVs with low SoC would not get higher charging powers even if needed. In smart charging, the amount of charging power can vary and up to three EVs are allowed to charge in three-phase simultaneously. This results that all the EVs get enough charging power, even if charged less than 8 hours in a day.

The cost for the energy becomes cheaper with smart charging, as seen from Table 13. If using the spot prices, the energy savings per day vary from 0 up to almost 2 euros. On average the difference is 53 cents per day, which seems like a small difference, but in a year, it becomes over hundred euros. With the general tariff, the cost remains the same for smart and stand-alone charging, as long as same amount of energy is consumed. However, since in smart charging the chargers can communicate with each other and with the building management system, most likely less energy is consumed than with stand-alone charging, where all the energy that is available is going to be used suboptimally.

Furthermore, not all 14 charging stations are in use already at 6 or 7 o'clock in the morning and the results will be distorted if this is not taken into account. As seen from Figure 9, most of the EV charging events actually occurs between 8:00 and 18:00. If calculating that all the electricity available is used for EV charging already at 6:00 or 7:00, the electricity cost would be much higher than in reality. By taking only the hours between 8:00 to 18:00 into account for both smart and stand-alone charging, the economic benefits of smart charging start to really show, as seen in

Table 15. The cost difference varies now between 1,73 € up to 7,44 € with the spot prices and on average, with smart charging the savings becomes 3,92 € per day.

Table 15: Differences in Sola's energy prices between 8:00 and 18:00.

Dates	Stand-alone [€]	Smart [€]	Difference [€]
14.01.2018	20,49	18,76	1,73
18.01.2019	37,85	34,41	3,44
24.01.2019	65,54	58,10	7,44
18.02.2019	30,58	27,51	3,07

If calculating the same costs with the general tariff of 6,34572 c/kWh, the average savings obtained with smart charging become even higher. The cost for stand-alone charging between 8:00 and 18:00 with the general tariff becomes 42,52 € (C7), when with smart charging the daily cost is only 38,16 € (C6), i.e., 4,36 € cheaper per day.

One notable thing is that the smart chargers cost around 250 € more than the stand-alone chargers. On top of this, in the EVlink Wallbox Plus stand-alone chargers, only Type A RCD is needed since the RDC-DD is included in the charger. The smart chargers need the Type B RCD since the RDC-DD is not included, which is around 60 € more expensive than the Type A RCD. Due to this, the total cost difference per charging point becomes around 310 €.[77] Furthermore, the smart charging requires the communication between the chargers and the cloud based back-end system. The communication link needs to be added, which costs around 2 000 €. This results in a total cost difference of 6 340 € for the 14 charging points including the communication with the back-end system. However, since the Canalis was used instead of traditional cabling, it saved around 3 800 €, resulting in a price difference of 2 540 € in favor of the stand-alone chargers.[78] Furthermore, the integration of the smart building management system to Sola cost around 6 000 €. This cost included the energy meters, which monitor the electricity consumption in the building, the software licence and the workload. By adding this expense to the installation costs of the chargers, the smart system is around 8 550 € more expensive than the stand-alone system.

Although the investment cost for the smart system is more expensive, the smart system provides almost 4 euros energy cost savings per day if used the spot prices in the calculations. With an assumption that EV charging occurs on 260 days in a year by taking only weekdays into account, the savings with the smart system become a little over 1 000 € in a year, resulting in an 8,5 year pay-back time. Furthermore, with the general tariff, the cost savings are even higher, being 4,35 € per day. In a year, the savings become over 1 100 € resulting in a 7,5 year pay-back time. These results presume that all 14 EV chargers are in use every day and that the electricity consumption in Sola follows the calculated values. With an investment plan of 10 years, the smart system saves between 1 500 € and 3 000 € compared to the stand-alone system. Economically, the calculated pay-back times are quite long and during 10 years, not that much of savings can be achieved. However, if considering that the chargers lifetime is around 20 years, between 12 000 € and 14 000 € in electricity costs are saved with smart charging after the pay-back time depending on the tariff used. Of course, the chargers may require some maintenance, but the expected lifetime of the hardware is around 20 years.

One important aspect to realize is that these calculations have not taken into account the costs for using either one of the main switch boards as an electricity source or the cost for building a new distribution board, discussed in Section 4.2 to be able to integrate stand-alone charging to Sola. The costs for increasing the fuse size and having non-optimized cables and CBs have also been taken out from the calculations. The reason for this is that it is impossible to know what cables or what CBs would alternatively have been used and which one of the supply alternatives would have been implemented if a stand-alone system would have been built in Sola instead of the smart one. Because of this, the pay-back time is actually even shorter for the smart system than calculated since all of these options increases the cost for the stand-alone charging. Finally, the comfort and reliability that the smart charging and load management system together brings for the employees, visitors and companies, is far more valuable than the cost.

Shopping center

In the Ideapark's case, 270 kWh of electricity is available every hour for both stand-alone charging and smart charging. The busiest charging hours are between 9:00 and 21:00, as seen from Figure 14, having the largest impact on the electricity consumption. During these 12 hours, a total of 3 240 kWh is reserved for EV charging per day, resulting that in one month, 97 200 kWh is used for the charging. However, with smart charging, the total consumption limit is set at 3 000 kW each hour, meaning that during some peak hours, less than 270 kWh of electricity is available for the charging.

The electricity cost becomes cheaper with smart charging than with stand-alone charging. With the general tariff, the price difference is 0,76 € per day and with the spot prices, the smart charging saves between 0,71 € and 1,44 €, as seen from Table 14. The average saving with the spot prices becomes 1,01 € per day. In a year, these price differences between stand-alone charging and smart charging results in savings between 270 € and 360 € depending on the tariff used.

Furthermore, during April 2019, when adding the 270 kWh of electricity reserved for EV charging on top of the basic consumption, the hourly limit of 3 000 kWh is exceeded 65 times. In total, 5 664 kWh of electricity has been over the 3 000 kWh limit during April. Since in stand-alone charging, all the 270 kWh of electricity is used regardless of the other loads, 5 664 kW more electricity is used with stand-alone charging compared to smart charging, where the consumption limit is set at 3 000 kWh. With the general tariff, the cost difference becomes:

$$5\ 664\ kWh * 6,34572\ c/kWh = 35\ 942,16\ c = 359,42\ € \tag{21}$$

During April 2019, almost 360 € in electricity is saved with smart charging. In a year, the difference becomes around 4 300 €, if assuming that every month follows the consumption of April. On top of this, the yearly savings of 270 € to 360 € are added resulting in total savings between 4 570 € and 4 660 € per year.

When considering the installation costs, the smart charging costs 2 000 € more than stand-alone charging due to the need for the communication link between the chargers and the back-end system. Also, the smart chargers cost 450 € more than the chargers used in stand-alone charging, since the smart charging requires chargers of 22 kW, whereas in stand-alone charging 7,4 kW chargers are enough to provide the power of 6,75 kW. With 20 chargers, the cost difference between stand-alone chargers and smart chargers becomes 9 000 €. By adding the cost of the communication link, the total difference is 11 000 €. However, due to the large savings of over 4 500 € in electricity costs yearly, the pay-back time is only two and a half years. If assuming that the investment is made over a 10 year period, the smart charging can save over 30 000 € compared to stand-alone charging in electricity costs. Furthermore, with an expected lifetime of 20 years for the chargers, it is possible to save over 70 000 € in electricity costs after the pay-back time. These results presume that all the 40 EV charging points are in use every day and that the electricity consumption follows the calculated values.

In these calculations the cost for implementing the BMS to Ideapark has not been taken into account as it is in Sola's case. The reason for this is that the cost for Ideapark's BMS is not known. Furthermore, with the BMS the operational costs in Ideapark are 40% smaller but the actual expenses are not known. Due to this, it is impossible to know how the implementation cost of the BMS relates to the achieved savings.

4.6 Survey results

In this section, the results of the survey made for Facility and Property Managers are reviewed. In total, 111 Facility Managers, Service Managers and Property Owners answered the survey, giving valuable insights into how they experience the need and importance of integrating EV chargers to buildings that they own or manage.

From the respondents, nine out of ten are able to influence the investment decisions regarding the purchasing of EV charging points. Geographically, the survey covers the whole Finland, since 48% of the respondents were from Southern Finland, 20% from Western and Inland Finland, 14% from Eastern Finland, 9% from South-Western Finland and the remaining 9% from Northern Finland. The buildings that the respondents manage include office buildings, stores, industrial buildings, residential buildings, hotels, hospitals, nursing homes and educational institutions.

Currently, a little over half the buildings in question already have EV charging points installed. In the buildings with EV chargers, the most common number is fewer than 5 charging points. In the rest of the buildings, the number is between 5 and 10 or over 10 charging points. Only a few of the respondents were uncertain about the number of EV charging points installed in their buildings. In the buildings with EV charging points installed, the main users are customers, visitors and employees. In 38% of the buildings, the chargers are in public usage, meaning that anyone can use them.

In buildings where EV chargers have not yet been installed, the most common reasons are that the issue is topical but no investment decisions have yet been made, the chargers are not perceived as necessary, no one has asked for chargers to be installed or the electricity supply of the property is not sufficient for installing EV chargers.

However, even though almost half of the buildings do not yet have EV chargers, within 2 years, 83% of the respondents believe that between 1 and 10 charging points will be installed in the buildings that they manage. Furthermore, up to 14% believe that the number of EV charging points will be even higher than 10. Only a few of the respondents believe that no charging points will be installed in their buildings. These new charging points would mainly be used by employees, guests and visitors, maintenance or be in public usage available for everyone. Regarding the type of the EV charger, 60% believe that smart chargers would be more beneficial to their building than stand-alone chargers. Especially smart charger features including the possibility of billing, visibility of energy used for charging, user identification and the optimization of charging time and power according to the building's own electricity consumption are seen as valuable and beneficial.

In the survey is one question about different responsibilities regarding the charging points. According to the respondents, the installation and commissioning of the chargers should either be the service provider's or contractor's responsibility. The management of access rights to the chargers as well as the invoicing of the usage should be managed either by Facility Managers or service providers. Both service and maintenance as well as customer support are seen as responsibilities of service providers according to the majority.

Information regarding EV charging points is found and asked from several different sources, including service providers, suppliers, partners, colleagues and different real estate magazines. Social media, Building Control Services and property management firms are also used as information sources. When Facility Mangers or building owners are thinking about purchasing EV charging points, they would contact first either service providers, panel builders, suppliers or electrical contractors. Few would also contact building contractors, energy companies as well as City Building Controls regarding the investment in EV charging points. Finally, when it comes to the financing of the EV chargers, 73% of the respondents think that a one-time investment is more interesting than a leasing model.

5 Discussion and conclusion

In this chapter the accuracy, reliability and strengths of this research are discussed. Furthermore, power quality issues and questions around taxation and environmental aspects are also reviewed. The results of the survey for Facility Managers are also discussed. At the end, the conclusion is drawn and some suggestions are given for further studying.

5.1 Discussion

In addition to discussing the pros and cons of this research, power quality issues related to EV charging are presented. This section also discuss vehicle taxation, environmental impacts and general opinions and thoughts around EVs and EV charging.

5.1.1 Accuracy, reliability and strengths

This thesis utilised heuristic method in the analysis of EV charging and its integration to buildings. For each case, the optimal way to organize the EV charging was calculated by hand after a number of trials, to get feasible results which satisfy the existing and set constraints. To calculate everything by hand with the help of Excel was laborious but possible with EV charging systems of a small scale. Moving to larger scale EV charging installations, another approach or method would possibly give more accurate results but on a small scale, the trial and error method was sufficient and transparent.

What affects the accuracy of the results are the assumptions made in the analysis and the calculations. In all of the cases, I have assumed that all of the chargers are in use continuously, which is not the situation in Sola nor Ideapark at the moment. For example in Sola, only half of the chargers and in Ideapark little over 30 charging points out of 40 have been used simultaneously so far. However, even if today not all of the charging points are in use, in few years the situation will presumably be different. Considering that the number of EVs continues to increase at the same rate or even faster, in both Sola and Ideapark most likely all of the charging points will be in use and the results of this thesis will become even more valuable and in line with the reality.

Furthermore, in Sola's case, the uncertainty of possible choices made if a stand-alone system would have been installed instead of the smart system affects the obtained economic results. Also in Ideapark's case, the lack of knowledge about the building management system's expenses as well as the savings Ideapark has achieved through the BMS may affect the financial results and findings discovered in this research.

Since this research is a qualitative research with limited quantitative analysis, the obtained results should be validated with more rigorous and larger sample size research to improve the reliability of this research. Several buildings of different sizes and types with EV charging should be studied to find out if those findings would be in line with the acquired results of this research.

The strengths of this thesis include the data on which the analyses are performed. Both the charging data as well as the load data from the buildings are real usage data from the sites. The charging data for both Ideapark and Sola was provided by Plugit, which is one of the leading CPOs in Finland. Moreover, the electricity consumption data for the buildings came from the buildings themselves, giving accurate and reliable data to conduct the analyses with. Also, when studied the technical benefits achieved with the smart system in both buildings, experts from Schneider Electric and Plugit were consulted to find out the advantages. Furthermore, the survey made for Facility and Property Managers validates the importance and the topicality of this research. According to the answers of the survey, the building owners and managers are currently struggling with the integration of EV chargers to their buildings due to the issue regarding the buildings electricity network, which are not built to withstand the additional loads originating from EV charging. To be able to show that it is possible to integrate EV charging into buildings without having the need of reinforce the electricity network due to optimization, can be considered being valuable for the building owners. Finally, the electricity prices used to calculate the economic benefits for both Sola and Ideapark are actual market prices taken from Nord Pool's own web sites. However, regarding the spot prices, only a limited sample of days were used to perform the economic calculations affecting the obtained results.

5.1.2 Power quality

Power quality is an important issue that needs to be taken into account when talking about EV charging. Since EV charging is a non-linear load, it has a negative impact on power quality. Possible quality problems that may occur are harmonic distortion, flicker and voltage unbalance. The IEEE Standard 519 defines the limits for the amount of harmonic distortion that individual customers can send back to the distribution grid. For voltage, the recommended distortion limit for the point of common coupling is 5%, and 3% for individual harmonics. The total THD (total harmonic distortion) limit is 8%, which cannot be exceeded.[79]

Currently for example in Sola, the THD for the whole EV charging installation varies between 0,5% and 3%, depending on how many charging points are in use. With the current system, the THD values are acceptable. However, there is a plan to install more charging stations in the near future, which may increase the THD. Similarly in Ideapark's case, if they are going to expand their EV charging network in the future, a recommendation would be to pay attention to the power quality. With 40 charging points, the amount of non-linear loads are already high and with an expansion, the number would increase even further and possibly cause some problems in the electrical system. In buildings where only couple of chargers are installed, no power quality issues will probably arise since the number of chargers are so few except if the power quality in the electrical system was poor from the beginning.

5.1.3 Taxation

Another interesting topic around EVs is the taxation and what will happen to it when transportation goes electric. Currently, as discussed earlier in the introduction, both the vehicle registration tax and the road tax are based on CO_2 emissions in Finland. Furthermore, transport fuels e.g. gasoline and diesel, are under heavy taxation. For example in 2015, 68% of the average price for 95 octane gasoline was composed of different taxes. The revenue from transportation has been increasing by 300 million each year from 2015, and in 2017, the Finnish government collected over 8,3 billion euros from the transportation sector. Especially the road tax and and the taxation on transport fuels have increased significantly each year to promote the sale of hybrids and EVs.[80] However, at some point, the revenue coming from the transportation sector will inevitably start to decrease when fewer people drive with conventional cars even if the taxation for road tax and transport fuels would continue to increase. This raises the question of whether the government needs to start to tax electric vehicles, to be able to collect similar amounts of money in the future also. One possible option would be to tax the electricity used for charging the EVs. However, it would be difficult to separate the electricity used for charging and the electricity used for other loads. A more realizable approach would be to tax driven kilometers instead, which would correlate with the electricity usage of the vehicle. This approach has already been proposed by a work group in the Finnish government in 2012, but it was left without support. The reason for this was that it would require continuous GPS (Global Positioning System) tracking of the car, which would violate the privacy of people.[81] Furthermore, what makes this issue even more difficult is that currently the heavy taxation on conventional cars has encouraged the sales of EVs. If the government starts to tax the EVs, it might stop their sale completely or at least slow it down since the EVs would loose one major competitive advantage against the conventional cars. How I see it, the taxation needs to be kept away from the EVs as long as the BEVs and hybrids are more expensive than the conventional cars. If the taxation is introduced too early, the EVs will become even more expensive and fewer people will be able to afford to buy one. However, if the price point is at the same level with conventional cars, I do not see any problem to introduce taxation for EVs at that point.

5.1.4 Environmental aspects

The main reason why the transportation sector is going electric is the climate change and CO_2 emissions. However, not many realize that producing an EV causes around 15% more emissions than producing a corresponding conventional car. For the largest EVs with battery range of 400 km, the emissions can be close to 70% higher than for a conventional car of the same size. The reason for this is the mining and processing of lithium and cobalt, which are needed in EV battery production. On the other hand, when looking at the total life time of the vehicles, the average emissions for EVs are around 50% less than with conventional cars. BEVs compensate their high production emissions within 2 years due to their usage of electricity instead of gasoline as fuel.[82] However, for hybrids, the compensation time is much longer because they use gasoline part of the time. Especially if driving only short distances infrequently, it may happen that the carbon footprint remains larger than if driving with a hybrid compared to a corresponding conventional car.

The compensation time of EV manufacturing varies also from country to country. In Germany, where 40% of the electricity is still produced with coal, for EVs to make up their manufacturing emissions, it may take up to 10 years of driving. The reason for this is the coal-fired power plants which produces the energy needed for manufacturing the EVs as well as the electricity used by the EVs. In France, where nuclear is the main source of energy, the carbon footprint of EVs are much smaller compared with Germany. Furthermore, in Norway, where hydroelectric power is the biggest source of energy, EVs may generate up to 60% less CO_2 emissions than conventional cars during their lifetime. Even in Poland, which is one of the most coal-reliant countries in the Europe, EVs have on average a 25% smaller carbon footprint compared to conventional cars.[12]

Even though for most of the time, an EV is a more environmentally friendly option in the long run when compared to a conventional car, the benefit the EV creates regarding the climate is very much dependent on how much the EV is used and in which country. It is noteworthy that in some cases it is possible that an EV would be worse for the climate than a conventional car due to the high emissions at the production phase and if the electricity used by the EV is produced with conventional energy sources.

5.1.5 Survey

To be able to discover what property managers and property owners think about integrating EV chargers to the buildings that they manage, a survey regarding EV charging was conducted. The questions and answers of the survey can be found in Appendix E. As stated before, in total, 111 Facility Managers, Service Managers and Property Owners answered the survey giving valuable information about how they feel about EV charging and its integration to buildings.

One important aspect is the fact that 90% of the respondents are able to influence the investment decisions regarding the purchasing of EV charging points to their properties, showing that the group of respondents was chosen correctly. Moreover, the answers came from all over Finland, giving an accurate picture of the current situation in our country. Furthermore, 70% of the respondents manage at least one commercial building, which is why the results and answers of the survey are highly relevant to this research.

Currently, a little over half of the buildings in question already have EV charging points installed. In the buildings with EV charging points, customers, visitors and employees use the charging points the most. In 38% of the buildings, the chargers are in public usage, meaning that anyone can use them. These results correspond well to the user groups that use the charging points analyzed in this research, since Sola's chargers are mainly used by the employees and customers and Ideapark's chargers are in public use.

In buildings where EV chargers have not yet been installed, the reasons presented in Section 4.6 are expected. The investment in the chargers is costly and if the owners do not think that they need to install EV chargers and especially if no one asks for them, it is understandable that they use the money for something else. Also, issues with the buildings' electricity networks, especially if they are not built to tolerate the additional loads originating from EV charging, prevent the building owners from purchasing EV chargers, even if they are seen as important and valuable for the users of the building.

What was also expected was that within 2 years, most of the respondents believe that EV charging points will be installed in the buildings that they manage. However, a small percentage of the respondents are still doubtful, believing that no charging points will be installed. Furthermore, more than half see that smart chargers would be more beneficial to their building than stand-alone chargers. From the smart chargers features, the possibility of billing, visibility of energy used for charging, user identification and the optimization of charging time and power according to the building's own electricity consumption are seen as valuable and beneficial. These features were also studied in this research, which has shown that the optimization of the charging times and charging powers according to the building's own electricity consumption may enable the property's electricity supply to after all, be sufficient for EV charging, solving one of the reasons why EV chargers have not yet been installed.

One interesting question in the survey is regarding the financing of the EV chargers. 73% of the respondents think that a one-time investment is a more attractive option than a leasing model. The result is interesting since the investments required for EV chargers are costly, which is also acknowledged by the Facility Managers. Paying for the chargers as a one-time investment, requires having a substantial amount of money available. The leasing-model on the other hand would enable the purchase of EV chargers without the need to make a large investment at once, which could solve some financial obstacles regarding purchasing and installation of EV chargers.

At the end of the survey, there was an open question regarding what thoughts the increasing number of EVs evoke. Overall, the general opinion regarding EVs and the need of installing EV chargers is positive. The EV chargers are seen as a green choice that reflects the building's values and increases the value of the building itself. They are also seen as a necessity to be able to increase the number of EVs in Finland further. However, there are also concerns that arise from the increasing number of EVs and EV charging. One concern is about the electricity network and its capacity to handle the additional loads originating from EV chargers. Both the adequacy of capacity in the buildings' own networks as well as in the national grid raise concerns among the respondents. Also the environmental impacts of producing the EV batteries, which requires mining of lithium and cobalt and the rising amount of battery waste from used batteries are seen as major concerns. Finally, the issue with the electricity production environmental friendliness as discussed in Section 5.1.4 is also raised by the participants. However, as seen in this research, with smart EV charging together with a smart building management system, it is possible to add EV chargers to buildings without exceeding the capacity limits of the buildings own network. The integration of EV chargers into buildings requires data analysis, simulations and calculations but, as shown in this research, the existing network may handle the additional loads if the EV charging is managed in a smart and optimal way. However, battery production and battery waste as well as electricity production with conventional fossil fuel sources are valid concerns and issues that need to be solved.

5.2 Conclusion

In this research, different aspects regarding EV charging and its integration to commercial buildings have been discussed. This research has shown that several technical requirements have to be taken into account to be able to integrate smart charging into smart buildings. This research has also studied if any technical and economic benefits are possible to be achieved by integrating smart charging into smart buildings instead of stand-alone charging into buildings without BMS. The results show that both technical and economic benefits can be achieved with a smart system compared to a stand-alone system. Even though the cost of implementing smart charging instead of stand-alone charging is more expensive, in the long rung, smart charging will use less electricity and generate smaller electricity bills, becoming a more profitable option. To the technical benefits include the possibility of using the existing electricity supply in the building for the EV charging, optimization of different components and being able provide customer service and support for the employees, visitors and guests who uses the chargers. Furthermore, compared to a stand-alone system, a smart system provides higher reliability, the possibility to avoid making reinforcements in the electrical system and more satisfied customers.

The results of this thesis were obtained heuristically. For each case, the optimal way of organizing the EV charging was calculated by hand from a number of tests. The heuristic technique is possible to be utilized with EV charging on a small scale as in this research, but assuming that EV chargers become more common in the near future, it will not be reasonable nor cost-effective to calculate everything manually. For future study, I would suggest to explore how machine learning could be used to optimize EV charging in buildings. Especially supervised learning algorithms that include a set of inputs and desired outputs could be used in the optimization. The users of the EV chargers, their vehicles and the buildings own electricity consumption data would be the inputs and the desired outputs fully charged batteries after a specific time without compromising the buildings own electricity system. The load management system in the chargers could then learn how the users behave i.e. how long they usually charge their EVs in that specific location and how the building in question consumes electricity and adjust the available charging power automatically accordingly to the presumed charging time and the capacity which the EV can receive.

Another study suggestion is to explore if it would be possible to have the users decide the charging time for their EVs manually. The chargers could have for example a display from which the users could choose the preferred charging time, the SoC of their vehicles battery and the maximum charging power that their EV can receive. From these inputs, the chargers LMS would then calculate the most optimal charging model for the EV in question. Of course also in this method, any capacity limits or other constraints have to be taken into account in the optimization, which may have a negative affect on the charging times.

6 Summary

EV charging is an expanding business due to the increasing uptake in electric vehicles in the past few years. Finland has set a target to reach 250 000 EVs during the following decade. However, this goal will not be achieved without implementing EV charging points at the same rate. This raises challenges in the infrastructure since it is not planned from the beginning to withstand the additional loads originating from EV charging. To be able to implement the chargers to the existing infrastructure and especially to the different buildings where most of the charging events take place, these additional loads need to be managed in a sufficient way. One option would be to combine data from building management systems with data coming from EV charging to be able to organize the charging by utilizing the existing electricity system and without any risk of exceeding capacity limits in the system.

This thesis studied EV charging in commercial buildings. Both stand-alone EV charging without integration to any BMS, as well as smart EV charging which was integrated to a smart building management system was studied. These two scenarios were analyzed and the differences both technically and economically compared for two different commercial building types. The buildings where a shopping center representing public charging and an office building representing semi-public charging. In stand-alone charging, there is no control of the charging since the chargers are not connected to any smart controlling system. Once the EV is plugged in, the charging starts immediately and ends when the battery has been filled or the user ends the charging. This practice may lead to very high charging costs, since the charging may take place during the peak hours when the electricity prices are at the highest. Smart charging on the other hand consists of an active charging management system, which controls and monitors the charging continuously. It also makes sure that no predefined capacity limits are being exceeded. Through smart charging, it is also possible to schedule the charging to hours where the basic electricity consumption and the electricity prices are lower.

The research goals for this thesis were to find out if any technical and economic benefits can be achieved by combining smart charging into a smart building with a BMS compared to a stand-alone system. The aim was also to study what kind of technical requirements are needed for implementing smart charging into smart buildings altogether.

This research shows that EV charging can be optimized with smart charging together with a smart building management system, resulting in savings in the electricity bill and without having the need for reinforcing the existing electrical system. Even though the investment of the smart system is more expensive compared to the stand-alone system, the acquired savings in the electricity consumption are significant that the smart system becomes more profitable and beneficial during the charger's lifetime in both studied cases. In the office building with fewer charging points, the pay-back time is around 8 years, saving over 10 000 € in the electricity costs during the charger's lifetime. With regard to the electricity tariffs, the general tariff seems to be a cheaper option resulting in larger savings and a shorter pay-back time compared to the spot-prices. In the shopping center with 40 charging points, the pay-back time is only little over 2,5 years and gives savings in the electricity bill of over 70 000 € during the charger's lifetime. These results imply that especially large systems benefit from smart charging when connected to the building's BMS.

To the technical benefits achieved with a smart system when compared with a stand-alone system include the possibility of using the existing electricity supply in the building for EV charging, optimization of different components, including CBs and cable thicknesses, and being able provide customer service and support for the employees, visitors and guests who uses the EV chargers. Furthermore, there are a large number of technical requirements that must be considered when implementing smart charging into smart buildings. Several of the requirements come from standards and can not be dismissed, including IK and IP levels, approved charging connectors and level of protection. Furthermore, the chargers need to be able to perform load management features, which are deferred start, current limitation and load shedding. Phase rotation and phase balancing must also to be taken into account to be able to minimize the maximum currents and powers.

Since EV charging is still quite a new but rapidly growing area, it needs further investigation and research. Especially machine learning algorithms could possibly be utilized to analyze EV charging in buildings in a larger scale to validate the obtained results from this research. They could also be used as help to create more efficient methodologies to study EV charging and its optimization in the future. Finally, although this research has only studied two different commercial buildings with EV charging, it serves as a guideline for what benefits smart charging together with BMS can bring to the buildings, its owners and its users.

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A EVlink Smart Wallbox

This appendix describes the technical characteristics of the EVlink Smart Wallbox used in this study.

Power supply network
- Smart Wallbox can be supplied either in single-phase or in three-phase
- 220 - 240 V single-phase – 50/60 Hz
- 380 - 415 V three-phase – 50/60 Hz
- Earthing diagrams:
  - TT, TN-S, TN-C-S
  - IT (may require the addition of an isolating transformer for charging of certain vehicles)

Rated charging current
- T2/T2S socket outlet: 8 A to 32 A (factory setting 16 A)
- TE socket outlet: 10 A

Power consumption
- Power consumption of each conditional input (limitation and deferred start): 5 mA 24 V DC

Mechanical and environmental characteristics
- Ingress protection code: IP55
- Impact protection code: IK10
- Operating temperature: -30°C to +50°C
- Storage temperature: -40°C to +80°C
- Attached cable length: 4.5 m

Charging access
- Key locking
- User authentication through a RFID badge. Remote authentication by supervision or local setting of authorized badges
  - 13.56 MHz RFID reader for badges with chips Mifare Ultralight, Mifare Classic 1K / 4K, I Code SLI, Tag-it HFI, EM4135 ... (under ISO/IEC 14443 A&B, ISO/IEC 15693 protocols) Notes: RFID badges available on the market and standard are modified very often, so we advice to carry out prior test on our charging station to check compatibility
  - 10 RFID badges provided with every RFID-type charging station

Energy metering
- Integrated measuring of the apparent power
- Interface with an external MID energy meter

Connectivity

- Wired Ethernet: 3 ports
  - Port 1: LAN
  - Port 2: Wi-Fi or GPRS
  - Port 3: connection to PC for commissioning
- Wi-Fi module as an accessory
- GPRS/3G modem as an accessory
- OCPP 1.5 or OCPP 1.6 interface

Commissioning

- Parameters setting through a web server embedded in the charging station.

Warranty

- 24 months for the entire EVlink range

Standards

- IEC/EN 61851-1 ed 2.0
- IEC/EN 61851-22 ed 1.0
- IEC/EN 62196-1 ed 2.0
- IEC/EN 62196-2 ed 1.0

B EVlink Parking

This appendix describes the technical characteristics of the EVlink Parking used in this study.

Power supply network

- EVlink Parking can be supplied either in single-phase or in three-phase
- Socket outlet supply circuit (1 circuit per socket outlet):
  - 220 - 240 V single-phase – 50/60 Hz
  - 380 - 415 V three-phase – 50/60 Hz
- Control circuit voltage (for charging station):
  - 220 - 240 V single-phase – 50/60 Hz
- Earthing diagrams:
  - TT, TN-S, TN-C-S
  - IT (may require the addition of an isolating transformer for charging of certain vehicles)

Charging modes

- Mode 2 with:
  - 10 A / Type E (FR standard) domestic socket
  - 10 A / Type F (DE standard) domestic socket
- Mode 3 with T2 socket outlet (with or without shutter)
- Communication between charging station and vehicle via charging cable as per IEC 61851

Mechanical and environmental characteristics

- Painted steel body, anti-corrosion treatment
- Protection: IP54 (IEC 60529), IK10 (IEC 62262)
- Operating temperature: -25°C to +40°C for Mode 2 / Mode 3 charging station
- Operating temperature: -25°C to +50°C for Mode 3 only charging station

Charging access

User authentication through a RFID badge. Remote authentication by supervision or local setting of authorized badges

- 13.56 MHz RFID reader for badges with chips Mifare Ultralight, Mifare Classic 1K / 4K, I Code SLI, Tag-it HFI, EM4135 ... (under ISO/IEC 14443 A&B, ISO/IEC 15693 protocols) Notes: RFID badges available on the market and standard are modified very often, so we advice to carry out prior test on our charging station to check compatibility
- 10 RFID badges provided with every RFID-type charging station

IT Network connection

- TCP/IP
- FTP, SMTP or HTTP data retrieval
- Operations:
  - remote user authentication
  - retrieve data for Charging Data Record
  - charging station status monitoring
  - get remote commands

Certification

- CE and CB scheme
- EV and ZE ready

Warranty

- 24 months for the entire EVlink range

Standards

- IEC/EN 61851-1
- IEC/EN 61851-22

C Energy cost calculations for Sola

The electricity consumption during working hours without EV charging included:

$$(143 + 199 + 254 + 260 + 265 + 298 + 249 + 238 + 229 + 200 + 175 + 140)\ kWh \\ = 2\ 650\ kWh \quad \text{(C1)}$$

The energy tax for the electricity consumption:

$$2,79372\ c/kWh * 2\ 650\ kWh = 7\ 403,36\ c = 74,03\ € \quad \text{(C2)}$$

The electricity consumption for smart EV charging during working hours when the powers are divided evenly between the chargers:

$$(100 + 100 + 46 + 40 + 35 + 2 + 51 + 62 + 71 + 100 + 100 + 100)\ kWh \\ = 807\ kWh \quad \text{(C3)}$$

The electricity consumption for smart EV charging during working hours when the powers varies between the chargers:

$$(99,4 + 99,4 + 46 + 40 + 34 + 2 + 50 + 61 + 70,2 + 99,4 + 99,4 + 99,4)\ kWh \\ = 800,2\ kWh \quad \text{(C4)}$$

The electricity consumption for smart EV charging during 8:00 and 18:00:

$$(46 + 40 + 34 + 2 + 50 + 61 + 70,2 + 99,4 + 99,4 + 99,4)\ kWh \\ = 601,4\ kWh \quad \text{(C5)}$$

The cost for smart charging during 8:00 and 18:00 with the general tariff:

$$6,34572\ c/kWh * 601,4\ kWh = 3\ 816\ c = 38,16\ € \quad \text{(C6)}$$

The cost for stand-alone charging during 8:00 and 18:00 with the general tariff:

$$6,34572\ c/kWh * 67\ kW * 10h = 4\ 252\ c = 42,52\ € \quad \text{(C7)}$$

The energy tax for the electricity used for stand-alone charging:

$$2,79372\ c/kWh * 804\ kWh = 2\ 246\ c = 22,46\ € \quad \text{(C8)}$$

The energy tax for the electricity used for smart charging:

$$2,79372\ c/kWh * 800,2\ kWh = 2\ 235\ c = 22,35\ € \quad \text{(C9)}$$

14.01.2018

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C10 shows the calculations for the first hour (06-07):

$$143\ kWh * \frac{28,35}{1000}\ €/kWh = 4,05\ € \tag{C10}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C1.

Table C1: Hourly energy costs for 14.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	143	28,35	4,05
07-08	199	28,55	5,68
08-09	254	28,83	7,32
09-10	260	29,41	7,65
10-11	265	29,74	7,88
11-12	298	30,13	8,98
12-13	249	29,81	7,42
13-14	238	29,44	7,01
14-15	229	29,94	6,86
15-16	200	31,32	6,26
16-17	175	33,27	5,82
17-18	140	33,98	4,76

The total energy cost without taxes is:

$$\begin{aligned}(4,05 + 5,68 + 7,32 + 7,65 + 7,88 + 8,98 + 7,42 + 7,01 + 6,86 +\\ + 6,26 + 5,82 + 4,74)\ € = 79,69\ €\end{aligned} \tag{C11}$$

The total energy cost including taxes:

$$79,69\ € + 74,03\ € = 153,72\ € \tag{C12}$$

The electricity cost for stand-alone charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C13 shows the calculations for the first hour (06-07):

$$67\ kWh * \frac{28,35}{1000}\ €/kWh = 1,90\ € \tag{C13}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C2.

Table C2: Hourly stand-alone charging costs for 14.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	67	28,35	1,90
07-08	67	28,55	1,91
08-09	67	28,83	1,93
09-10	67	29,41	1,97
10-11	67	29,74	1,99
11-12	67	30,13	2,02
12-13	67	29,81	2,00
13-14	67	29,44	1,97
14-15	67	29,94	2,01
15-16	67	31,32	2,10
16-17	67	33,27	2,23
17-18	67	33,98	2,28

The total energy cost without taxes is:

$$(1,90 + 1,91 + 1,93 + 1,97 + 1,99 + 2,02 + 2,00 + 1,97 + 2,01 + \\ + 2,10 + 2,23 + 2,28) \text{ €} = 24,31 \text{ €} \quad \text{(C14)}$$

The total energy cost including taxes:

$$24,31 \text{ €} + 22,46 \text{ €} = 46,77 \text{ €} \quad \text{(C15)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C16 shows the calculations for the first hour (06-07):

$$99,4\ kWh * \frac{28,35}{1000} \text{ €}/kWh = 2,82 \text{ €} \quad \text{(C16)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C3.

The total energy cost without taxes is:

$$(2,82 + 2,84 + 1,33 + 1,18 + 1,01 + 0,06 + 1,49 + 1,80 + 2,10 + \\ + 3,11 + 3,31 + 3,38) \text{ €} = 24,42 \text{ €} \quad \text{(C17)}$$

Table C3: Hourly smart charging costs for 14.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	99,4	28,35	2,82
07-08	99,4	28,55	2,84
08-09	46,0	28,83	1,33
09-10	40,0	29,41	1,18
10-11	34,0	29,74	1,01
11-12	2,0	30,13	0,06
12-13	50,0	29,81	1,49
13-14	61,0	29,44	1,80
14-15	70,2	29,94	2,10
15-16	99,4	31,32	3,11
16-17	99,4	33,27	3,31
17-18	99,4	33,98	3,38

The total energy cost including taxes:

$$24,42 \text{ €} + 22,35 \text{ €} = 46,77 \text{ €} \tag{C18}$$

18.01.2019

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C19 shows the calculations for the first hour (06-07):

$$143\ kWh * \frac{52,79}{1000} \text{ €}/kWh = 7,55 \text{ €} \tag{C19}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C4.

The total energy cost without taxes is:

$$(7,55 + 10,73 + 13,82 + 14,46 + 14,58 + 16,49 + 13,98 + 13,09 + 12,98 + \\ + 11,47 + 10,42 + 8,37) \text{ €} = 147,95 \text{ €} \tag{C20}$$

The total energy cost including taxes:

$$147,95 \text{ €} + 74,03 \text{ €} = 221,98 \text{ €} \tag{C21}$$

Table C4: Hourly energy costs for 18.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	143	52,79	7,55
07-08	199	53,94	10,73
08-09	254	54,42	13,82
09-10	260	55,62	14,46
10-11	265	55,00	14,58
11-12	298	55,35	16,49
12-13	249	56,14	13,98
13-14	238	55,02	13,09
14-15	229	56,68	12,98
15-16	200	57,33	11,47
16-17	175	59,53	10,42
17-18	140	59,80	8,37

The electricity cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C22 shows the calculations for the first hour (06-07):

$$67\ kWh * \frac{52,74}{1000}\ €/kWh = 3,53\ € \tag{C22}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C5.

Table C5: Hourly stand-alone charging costs for 18.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	67	52,74	3,53
07-08	67	53,94	3,61
08-09	67	54,42	3,65
09-10	67	55,62	3,73
10-11	67	55,00	3,69
11-12	67	55,35	3,71
12-13	67	56,14	3,76
13-14	67	55,02	3,69
14-15	67	56,68	3,80
15-16	67	57,33	3,84
16-17	67	59,53	3,99
17-18	67	59,80	4,01

The total energy cost without taxes is:

$$(3,53+3,61+3,65+3,73+3,69+3,71+3,76+3,69+3,80+ \\ +3,84+3,99+4,01)\text{ €} = 45,00\text{ €} \quad \text{(C23)}$$

The total energy cost including taxes:

$$45,00\text{ €} + 22,46\text{ €} = 67,46\text{ €} \quad \text{(C24)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C25 shows the calculations for the first hour (06-07):

$$99,4\ kWh * \frac{52,74}{1000}\text{ €}/kWh = 5,24\text{ €} \quad \text{(C25)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C6.

Table C6: Hourly smart charging costs for 18.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	99,4	52,74	5,24
07-08	99,4	53,94	5,36
08-09	46	54,42	2,50
09-10	40,0	55,62	2,22
10-11	34,0	55,00	1,87
11-12	2,0	55,35	0,11
12-13	50,0	56,14	2,81
13-14	61,0	55,02	3,36
14-15	70,2	56,68	3,98
15-16	99,4	57,33	5,70
16-17	99,4	59,53	5,92
17-18	99,4	59,80	5,94

The total energy cost without taxes is:

$$(5,24+5,36+2,50+2,22+1,87+0,11+2,81+3,36+3,98+ \\ +5,70+5,92+5,94)\text{ €} = 45,01\text{ €} \quad \text{(C26)}$$

The total energy cost including taxes:

$$45,01\text{ €} + 22,35\text{ €} = 67,36\text{ €} \quad \text{(C27)}$$

24.01.2019

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C28 shows the calculations for the first hour (06-07):

$$143\ kWh * \frac{75,98}{1000}\ €/kWh = 10,87\ € \tag{C28}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C7.

Table C7: Hourly energy costs for 24.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	143	75,98	10,87
07-08	199	96,70	19,24
08-09	254	109,45	27,80
09-10	260	107,67	27,99
10-11	265	98,06	25,99
11-12	298	100,37	29,91
12-13	249	95,18	23,70
13-14	238	89,67	21,34
14-15	229	87,70	20,08
15-16	200	88,28	17,66
16-17	175	95,01	16,63
17-18	140	106,82	14,95

The total energy cost without taxes is:

$$\begin{aligned}(10,87 + 19,24 + 27,80 + 27,99 + 25,99 + 29,91 + 23,70 + 21,34 + 20,08 +\\ + 17,66 + 16,63 + 14,95)\ € = 256,16\ €\end{aligned} \tag{C29}$$

The total energy cost including taxes:

$$256,16\ € + 74,03\ € = 330,19\ € \tag{C30}$$

The electricity cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C31 shows the calculations for the first hour (06-07):

$$67\ kWh * \frac{75,98}{1000}\ €/kWh = 5,09\ € \tag{C31}$$

Table C8: Hourly stand-alone charging costs for 24.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	67	75,98	5,09
07-08	67	96,70	6,48
08-09	67	109,45	7,33
09-10	67	107,67	7,21
10-11	67	98,06	6,57
11-12	67	100,37	6,72
12-13	67	95,18	6,38
13-14	67	89,67	6,01
14-15	67	87,70	5,88
15-16	67	88,28	5,91
16-17	67	95,01	6,37
17-18	67	106,82	7,16

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C8.

The total energy cost without taxes is:

$$(5,09 + 6,48 + 7,33 + 7,21 + 6,57 + 6,72 + 6,38 + 6,01 + 5,88 + \\ + 5,91 + 6,37 + 7,16) \text{ €} = 77,11 \text{ €} \quad \text{(C32)}$$

The total energy cost including taxes:

$$77,11 \text{ €} + 22,46 \text{ €} = 99,57 \text{ €} \quad \text{(C33)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C34 shows the calculations for the first hour (06-07):

$$99,4\ kWh * \frac{75,98}{1000} \text{ €}/kWh = 7,55 \text{ €} \quad \text{(C34)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C9.

The total energy cost without taxes is:

$$(7,55 + 9,61 + 5,03 + 4,31 + 3,33 + 0,20 + 4,76 + 5,47 + 6,16 + \\ + 8,78 + 9,44 + 10,62) \text{ €} = 75,26 \text{ €} \quad \text{(C35)}$$

Table C9: Hourly smart charging costs for 24.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	99,4	75,98	7,55
07-08	99,4	96,70	9,61
08-09	46,0	109,45	5,03
09-10	40,0	107,67	4,31
10-11	34,0	98,06	3,33
11-12	2,0	100,37	0,20
12-13	50,0	95,18	4,76
13-14	61,0	89,67	5,47
14-15	70,2	87,70	6,16
15-16	99,4	88,28	8,78
16-17	99,4	95,01	9,44
17-18	99,4	106,82	10,62

The total energy cost including taxes:

$$75,26 \text{ €} + 22,35 \text{ €} = 97,61 \text{ €} \tag{C36}$$

18.02.2019

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C37 shows the calculations for the first hour (06-07):

$$143\ kWh * \frac{47,92}{1000} \text{ €}/kWh = 6,85 \text{ €} \tag{C37}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C10.

The total energy cost without taxes is:

$$\begin{split}(6,85 + 9,41 + 11,84 + 12,10 + 12,30 + 13,44 + 10,99 + 10,46 + 10,25 + \\ + 9,11 + 8,06 + 6,62) \text{ €} = 121,44 \text{ €}\end{split} \tag{C38}$$

The total energy cost including taxes:

$$121,44 \text{ €} + 74,03 \text{ €} = 195,47 \text{ €} \tag{C39}$$

Table C10: Hourly energy costs for 18.02.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	143	47,92	6,85
07-08	199	47,29	9,41
08-09	254	46,60	11,84
09-10	260	46,54	12,10
10-11	265	46,41	12,30
11-12	298	45,09	13,44
12-13	249	44,15	10,99
13-14	238	43,97	10,46
14-15	229	44,78	10,25
15-16	200	45,55	9,11
16-17	175	46,03	8,06
17-18	140	47,32	6,62

The electricity cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C40 shows the calculations for the first hour (06-07):

$$67\ kWh * \frac{47,92}{1000}\ €/kWh = 3,21\ € \tag{C40}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C11.

Table C11: Hourly stand-alone charging costs for 18.02.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	67	47,92	3,21
07-08	67	47,29	3,17
08-09	67	46,60	3,12
09-10	67	46,54	3,12
10-11	67	46,41	3,11
11-12	67	45,09	3,02
12-13	67	44,15	2,96
13-14	67	43,97	2,95
14-15	67	44,78	3,00
15-16	67	45,55	3,05
16-17	67	46,03	3,08
17-18	67	47,32	3,17

The total energy cost without taxes is:

$$(3,21 + 3,17 + 3,12 + 3,12 + 3,11 + 3,02 + 3,96 + 2,95 + 3,00 + \\ + 3,05 + 3,08 + 3,17) \text{ €} = 36,96 \text{ €} \quad \text{(C41)}$$

The total energy cost including taxes:

$$36,96 \text{ €} + 22,46 \text{ €} = 59,42 \text{ €} \quad \text{(C42)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. C43 shows the calculations for the first hour (06-07):

$$99,4 \; kWh * \frac{47,92}{1000} \text{ €}/kWh = 4,76 \text{ €} \quad \text{(C43)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table C12.

Table C12: Hourly smart charging costs for 18.02.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
06-07	99,4	47,92	4,76
07-08	99,4	47,29	4,70
08-09	46,0	46,60	2,14
09-10	40,0	46,54	1,86
10-11	34,0	46,41	1,58
11-12	2,0	45,09	0,09
12-13	50,0	44,15	2,21
13-14	61,0	43,97	2,68
14-15	70,2	44,78	3,14
15-16	99,4	45,55	4,53
16-17	99,4	46,03	4,58
17-18	99,4	47,32	4,70

The total energy cost without taxes is:

$$(4,76 + 4,70 + 2,14 + 1,86 + 1,58 + 0,09 + 2,21 + 2,68 + 3,14 + \\ + 4,53 + 4,58 + 4,70) \text{ €} = 36,98 \text{ €} \quad \text{(C44)}$$

The total energy cost including taxes:

$$36,98 \text{ €} + 22,35 \text{ €} = 59,33 \text{ €} \quad \text{(C45)}$$

D Energy cost calculations for Ideapark

The electricity consumption for stand-alone charging between 9:00 and 21:00:

$$12 * 270\ kWh = 3\ 240\ kWh \tag{D1}$$

The electricity consumption for smart charging between 9:00 and 21:00:

$$12 * 269\ kWh = 3\ 228\ kWh \tag{D2}$$

The energy tax for the basic electricity consumption between 9:00 and 21:00:

$$2,79372\ c/kWh * 30\ 858\ kWh = 86\ 208,61\ c = 862,09\ € \tag{D3}$$

The energy tax for the electricity used for stand-alone charging:

$$2,79372\ c/kWh * 3\ 240\ kWh = 9\ 051,65\ c = 90,52\ € \tag{D4}$$

The energy tax for the electricity used for smart charging:

$$2,79372\ c/kWh * 3\ 228\ kWh = 9\ 018,13\ c = 90,18\ € \tag{D5}$$

14.01.2018

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D6 shows the calculations for the first hour (09-10):

$$2\ 347\ kWh * \frac{29,41}{1000}\ €/kWh = 69,03\ € \tag{D6}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D1.

The total energy cost without taxes is:

$$\begin{split}(69,03 + 77,89 + 79,33 + 80,84 + 79,64 + 82,10 + 85,69 + 89,46 + 91,07 +\\ + 87,00 + 80,87 + 53,19)\ € = 956,10\ €\end{split} \tag{D7}$$

The total energy cost including taxes:

$$956,10\ € + 862,09\ € = 1\ 818,19\ € \tag{D8}$$

Table D1: Hourly energy costs for 14.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	2 347	29,41	69,03
10-11	2 619	29,74	77,89
11-12	2 633	30,13	79,33
12-13	2 712	29,81	80,84
13-14	2 705	29,44	79,64
14-15	2 742	29,94	82,10
15-16	2 736	31,32	85,69
16-17	2 689	33,27	89,46
17-18	2 680	33,98	91,07
18-19	2 677	32,50	87,00
19-20	2 577	31,38	80,87
20-21	1 741	30,55	53,19

The cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D9 shows the calculations for the first hour (09-10):

$$270\ kWh * \frac{29,41}{1000}\ €/kWh = 7,94\ € \tag{D9}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D2.

Table D2: Hourly stand-alone charging costs for 14.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	270	29,41	7,94
10-11	270	29,74	8,03
11-12	270	30,13	8,14
12-13	270	29,81	8,05
13-14	270	29,44	7,95
14-15	270	29,94	8,08
15-16	270	31,32	8,46
16-17	270	33,27	8,98
17-18	270	33,98	9,17
18-19	270	32,50	8,78
19-20	270	31,38	8,47
20-21	270	30,55	8,25

The total energy cost without taxes is:

$$(7,94+8,03+8,14+8,05+7,95+8,08+8,46+8,98+9,17+ \\ +8,78+8,47+8,25)\ € = 100,30\ € \quad \text{(D10)}$$

The total energy cost including taxes:

$$100,30\ € + 90,52\ € = 190,82\ € \quad \text{(D11)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D12 shows the calculations for the first hour (09-10):

$$269\ kWh * \frac{29,41}{1000}\ €/kWh = 7,91\ € \quad \text{(D12)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D3.

Table D3: Hourly smart charging costs for 14.01.2018.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	269	29,41	7,91
10-11	269	29,74	8,00
11-12	269	30,13	8,10
12-13	269	29,81	8,02
13-14	269	29,44	7,92
14-15	269	29,94	8,05
15-16	269	31,32	8,43
16-17	269	33,27	8,95
17-18	269	33,98	9,14
18-19	269	32,50	8,74
19-20	269	31,38	8,44
20-21	269	30,55	8,22

The total energy cost without taxes is:

$$(7,91+8,00+8,10+8,02+7,92+8,05+8,43+8,95+9,14+ \\ +8,74+8,44+8,22)\ € = 99,93\ € \quad \text{(D13)}$$

The total energy cost including taxes:

$$99,93\ € + 90,18\ € = 190,11\ € \quad \text{(D14)}$$

18.01.2019

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D15 shows the calculations for the first hour (09-10):

$$2\ 347\ kWh * \frac{55,62}{1000}\ €/kWh = 130,54\ € \tag{D15}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D4.

Table D4: Hourly energy costs for 18.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	2 347	55,62	130,54
10-11	2 619	55,00	144,05
11-12	2 633	55,35	145,74
12-13	2 712	56,14	152,25
13-14	2 705	55,02	148,83
14-15	2 742	56,68	155,42
15-16	2 736	57,33	156,85
16-17	2 689	59,53	160,08
17-18	2 680	59,80	160,26
18-19	2 677	58,06	157,43
19-20	2 577	53,85	138,77
20-21	1 741	53,05	92,36

The total energy cost without taxes is:

$$(130,54 + 144,05 + 145,74 + 152,25 + 148,83 + 155,42 + 156,85 + 160,08 + \\ + 160,26 + 155,43 + 138,77 + 92,36)\ € = 1\ 740,57\ € \tag{D16}$$

The total energy cost including taxes:

$$1\ 740,57\ € + 862,09\ € = 2\ 602,66\ € \tag{D17}$$

The cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D18 shows the calculations for the first hour (09-10):

$$270\ kWh * \frac{55,62}{1000}\ €/kWh = 15,02\ € \tag{D18}$$

Table D5: Hourly stand-alone charging costs for 18.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	270	55,62	15,02
10-11	270	55,00	14,85
11-12	270	55,35	14,94
12-13	270	56,14	15,16
13-14	270	55,02	14,86
14-15	270	56,68	15,30
15-16	270	57,33	15,48
16-17	270	59,53	16,07
17-18	270	59,80	16,15
18-19	270	58,06	15,68
19-20	270	53,85	14,54
20-21	270	53,05	14,32

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D5.

The total energy cost without taxes is:

$$(15,02 + 14,85 + 14,94 + 15,16 + 14,86 + 15,30 + 15,48 + 16,07 + 16,15 + \\ + 15,68 + 14,54 + 14,32) \text{ €} = 182,37 \text{ €} \quad \text{(D19)}$$

The total energy cost including taxes:

$$182,37 \text{ €} + 90,52 \text{ €} = 272,89 \text{ €} \quad \text{(D20)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D21 shows the calculations for the first hour (09-10):

$$269\ kWh * \frac{55,62}{1000} \text{ €}/kWh = 14,96 \text{ €} \quad \text{(D21)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D6.

The total energy cost without taxes is:

$$(14,96 + 14,80 + 14,89 + 15,10 + 14,80 + 15,25 + 15,42 + 16,01 + 16,09 + \\ + 15,62 + 14,49 + 14,27) \text{ €} = 181,69 \text{ €} \quad \text{(D22)}$$

Table D6: Hourly smart charging costs for 18.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	269	55,62	14,96
10-11	269	55,00	14,80
11-12	269	55,35	14,89
12-13	269	56,14	15,10
13-14	269	55,02	14,80
14-15	269	56,68	15,25
15-16	269	57,33	15,42
16-17	269	59,53	16,01
17-18	269	59,80	16,09
18-19	269	58,06	15,62
19-20	269	53,85	14,49
20-21	269	53,05	14,27

The total energy cost including taxes:

$$181,69 \text{ €} + 90,18 \text{ €} = 271,87 \text{ €} \tag{D23}$$

24.01.2019

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D24 shows the calculations for the first hour (09-10):

$$2\ 347\ kWh * \frac{107,67}{1000} \text{ €}/kWh = 252,70 \text{ €} \tag{D24}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D7.

The total energy cost without taxes is:

$$\begin{aligned}(252,70 + 256,82 + 264,27 + 258,13 + 242,56 + 240,47 + 241,53 + 255,48 + \\ + 286,28 + 268,48 + 189,10 + 105,07) \text{ €} = 2\ 860,89 \text{ €}\end{aligned} \tag{D25}$$

The total energy cost including taxes:

$$2\ 860,89 \text{ €} + 862,09 \text{ €} = 3\ 722,98 \text{ €} \tag{D26}$$

Table D7: Hourly energy costs for 24.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	2 347	107,67	252,70
10-11	2 619	98,06	256,82
11-12	2 633	100,37	264,27
12-13	2 712	95,18	258,13
13-14	2 705	89,67	242,56
14-15	2 742	87,70	240,47
15-16	2 736	88,28	241,53
16-17	2 689	95,01	255,48
17-18	2 680	106,82	286,28
18-19	2 677	100,29	268,48
19-20	2 577	73,38	189,10
20-21	1 741	60,35	105,07

The electricity cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D27 shows the calculations for the first hour (09-10):

$$270\ kWh * \frac{107,67}{1000}\ €/kWh = 29,07\ € \tag{D27}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D8.

Table D8: Hourly stand-alone charging costs for 24.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	270	107,67	29,07
10-11	270	98,06	26,48
11-12	270	100,37	27,10
12-13	270	95,18	25,70
13-14	270	89,67	24,21
14-15	270	87,70	23,68
15-16	270	88,28	23,84
16-17	270	95,01	25,65
17-18	270	106,82	28,84
18-19	270	100,29	27,08
19-20	270	73,38	19,81
20-21	270	60,35	16,29

The total energy cost without taxes is:

$$(29,07 + 26,48 + 27,10 + 25,70 + 24,21 + 23,68 + 23,84 + 25,65 + 28,84 + \\ + 27,08 + 19,81 + 16,29)\ € = 297,75\ € \quad \text{(D28)}$$

The total energy cost including taxes:

$$297,75\ € + 90,52\ € = 388,27\ € \quad \text{(D29)}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D30 shows the calculations for the first hour (09-10):

$$269\ kWh * \frac{107,67}{1000}\ €/kWh = 28,96\ € \quad \text{(D30)}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D9.

Table D9: Hourly smart charging costs for 24.01.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	269	107,67	28,96
10-11	269	98,06	26,38
11-12	269	100,37	27,00
12-13	269	95,18	25,60
13-14	269	89,67	24,12
14-15	269	87,70	23,59
15-16	269	88,28	23,75
16-17	269	95,01	25,56
17-18	269	106,82	28,73
18-19	269	100,29	26,98
19-20	269	73,38	19,74
20-21	269	60,35	16,23

The total energy cost without taxes is:

$$(28,96 + 26,38 + 27,00 + 25,60 + 24,12 + 23,59 + 23,75 + 25,56 + 28,73 + \\ + 26,98 + 19,74 + 16,23)\ € = 296,65\ € \quad \text{(D31)}$$

The total energy cost including taxes:

$$296,65\ € + 90,18\ € = 386,83\ € \quad \text{(D32)}$$

18.02.2019

The electricity cost for every hour is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D33 shows the calculations for the first hour (09-10):

$$2\ 347\ kWh * \frac{46,54}{1000}\ €/kWh = 109,23\ € \tag{D33}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D10.

Table D10: Hourly energy costs for 18.02.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	2 347	46,54	109,23
10-11	2 619	46,41	121,55
11-12	2 633	45,09	118,72
12-13	2 712	44,15	119,73
13-14	2 705	43,97	118,94
14-15	2 742	44,78	122,79
15-16	2 736	45,55	124,62
16-17	2 689	46,03	123,77
17-18	2 680	47,32	126,82
18-19	2 677	47,85	116,87
19-20	2 577	45,35	116,87
20-21	1 741	44,80	78,00

The total energy cost without taxes is:

$$\begin{aligned}(109,23 + 121,55 + 118,72 + 119,73 + 118,94 + 122,79 + 124,62 + 123,77 +\\ + 126,82 + 128,09 + 116,87 + 78,00)\ € = 1\ 409,13\ €\end{aligned} \tag{D34}$$

The total energy cost including taxes:

$$1\ 409,13\ € + 862,09\ € = 2\ 271,22\ € \tag{D35}$$

The electricity cost for stand-alone EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D36 shows the calculations for the first hour (09-10):

$$270\ kWh * \frac{46,54}{1000}\ €/kWh = 12,57\ € \tag{D36}$$

Table D11: Hourly stand-alone charging costs for 18.02.2019.

Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	270	46,54	12,57
10-11	270	46,41	12,53
11-12	270	45,09	12,17
12-13	270	44,15	11,92
13-14	270	43,97	11,87
14-15	270	44,78	12,09
15-16	270	45,55	12,30
16-17	270	46,03	12,43
17-18	270	47,32	12,78
18-19	270	47,85	12,92
19-20	270	45,35	12,24
20-21	270	44,80	12,10

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D11.

The total energy cost without taxes is:

$$(12,57 + 12,53 + 12,17 + 11,92 + 11,87 + 12,09 + 12,30 + 12,43 + 12,78 + \\ + 12,92 + 12,24 + 12,10)\ € = 147,92\ € \tag{D37}$$

The total energy cost including taxes:

$$147,92\ € + 90,52\ € = 238,44\ € \tag{D38}$$

The electricity cost for smart EV charging is calculated as the electricity consumption for each hour times the spot price for the corresponding hour. D39 shows the calculations for the first hour (09-10):

$$269\ kWh * \frac{46,54}{1000}\ €/kWh = 12,52\ € \tag{D39}$$

The same calculation is done for all the other hours. All the hourly costs can be seen in Table D12.

The total energy cost without taxes is:

$$(12,52 + 12,48 + 12,13 + 11,88 + 11,83 + 12,05 + 12,25 + 12,38 + 12,73 + \\ + 12,87 + 12,20 + 12,05)\ € = 147,37\ € \tag{D40}$$

Table D12: Hourly smart charging costs for 18.02.2019.

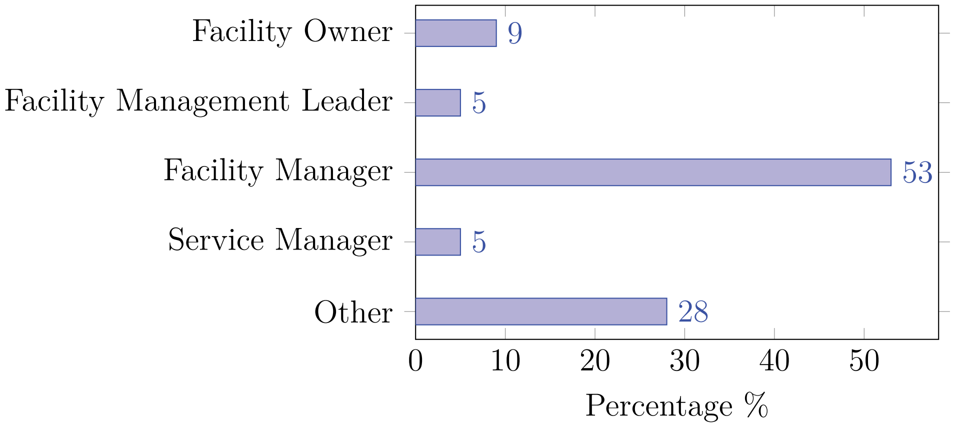
Time	Consumption (kWh)	Price (€/MWh)	Cost (€)
09-10	269	46,54	12,52
10-11	269	46,41	12,48
11-12	269	45,09	12,13
12-13	269	44,15	11,88
13-14	269	43,97	11,83
14-15	269	44,78	12,05
15-16	269	45,55	12,25
16-17	269	46,03	12,38
17-18	269	47,32	12,73
18-19	269	47,85	12,87
19-20	269	45,35	12,20
20-21	269	44,80	12,05

The total energy cost including taxes:

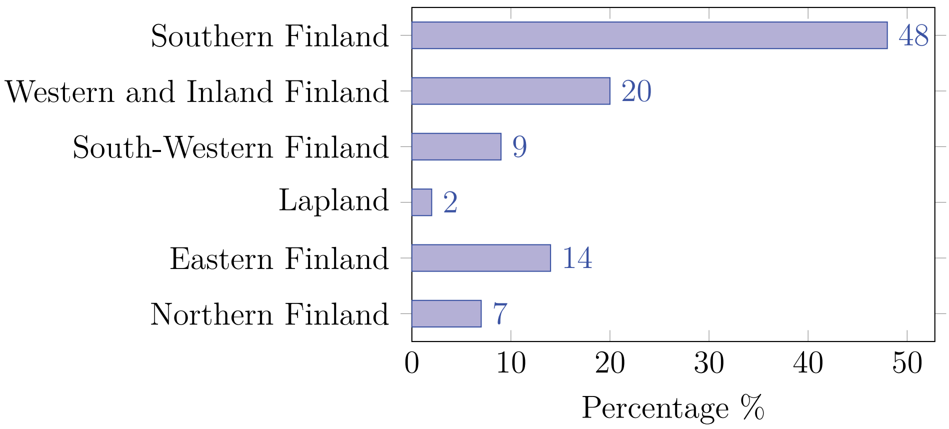
$$147,37\text{ €} + 90,18\text{ €} = 237,55\text{ €} \tag{D41}$$

E Survey questions and answers

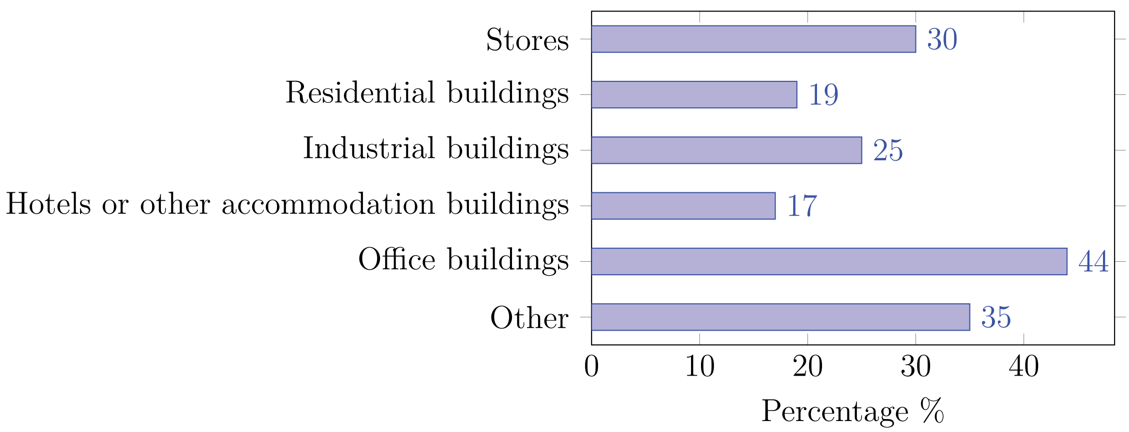
1. Your job description



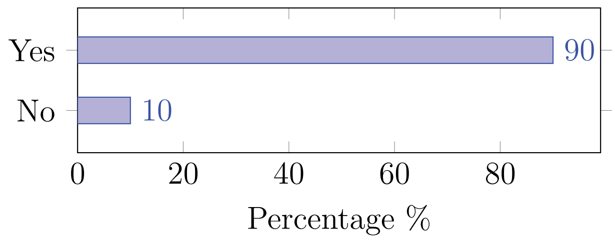
2. In which area do you mainly operate?



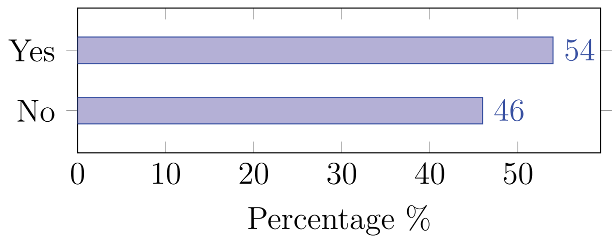
3. What kind of properties do you manage?



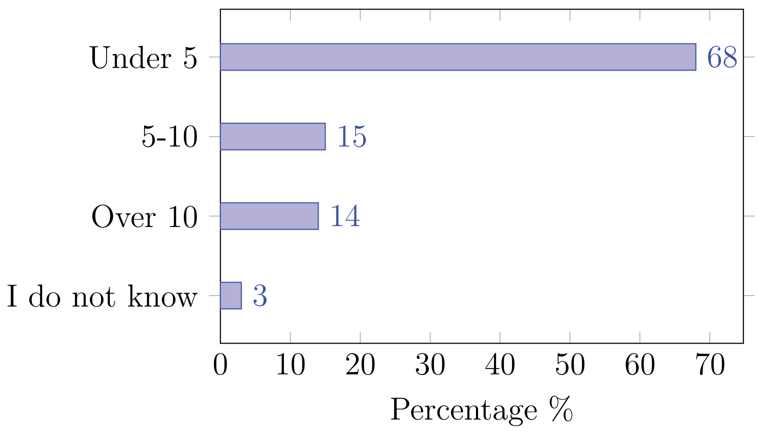
4. Are you able to influence the investment decisions regarding the procurement of EV charging points in your property?



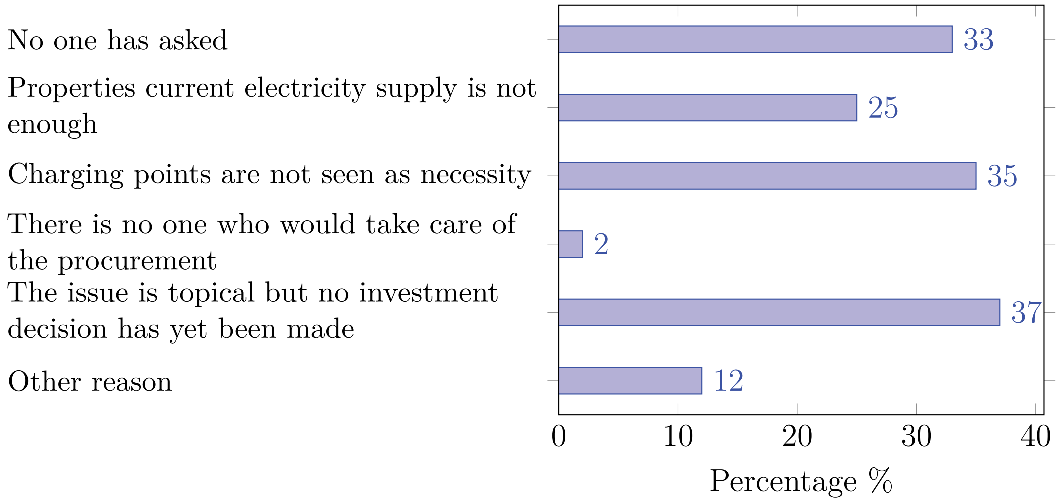
5. Do your property, which you manage, have already EV charging points?



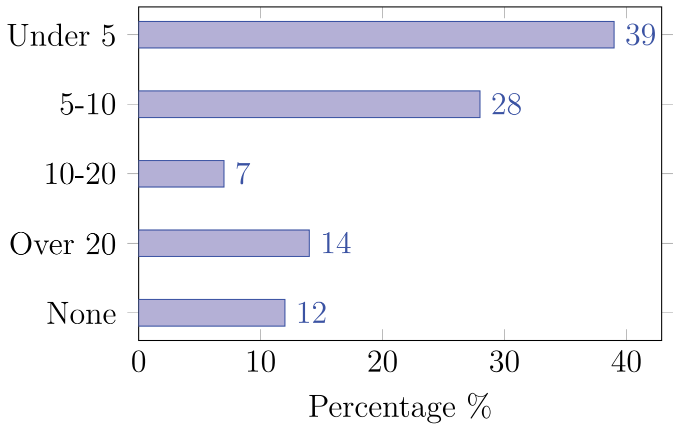
6. The average number of charging points in the property?



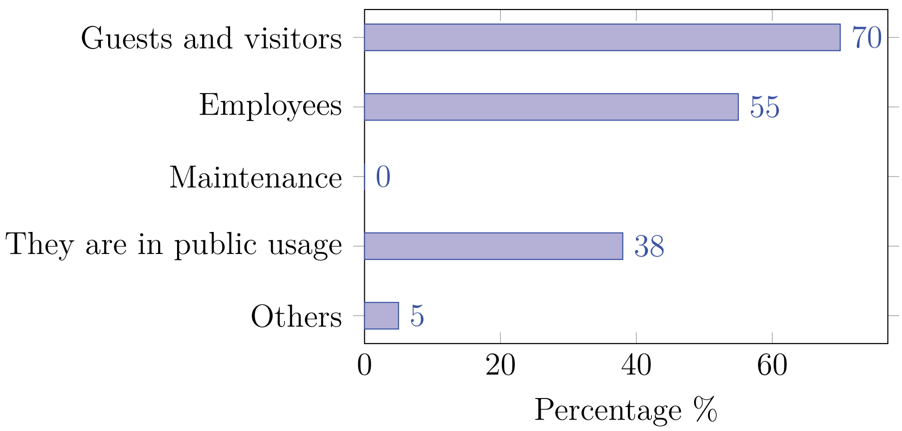
7. Why are there no EV charging points installed to the properties?



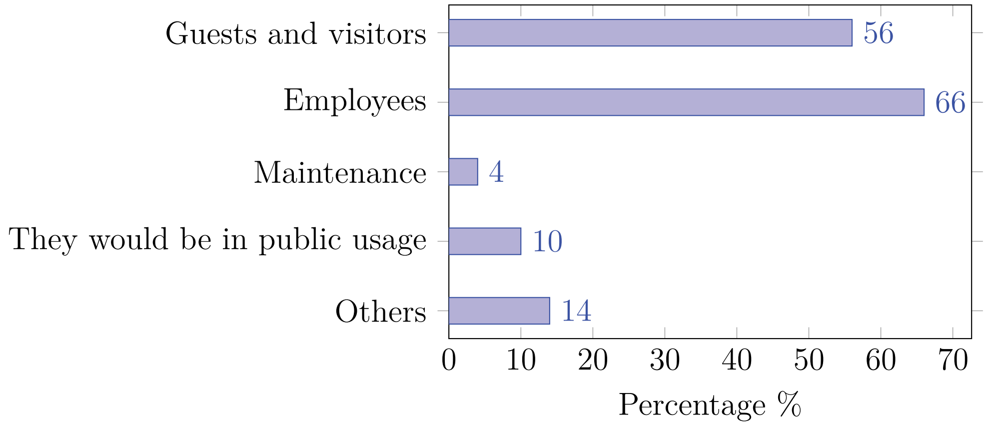
8. How many charging points do you expect to be installed on your managed property over the next 24 months?



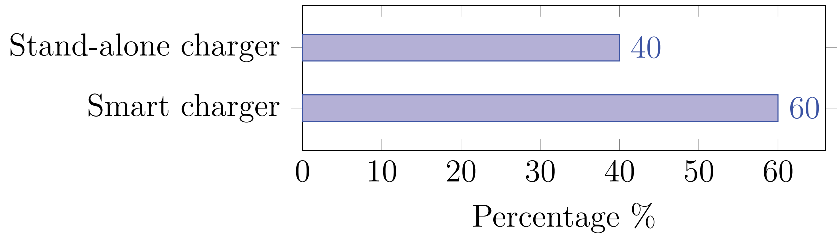
9. Who mainly uses the charging points in the properties that you manage?



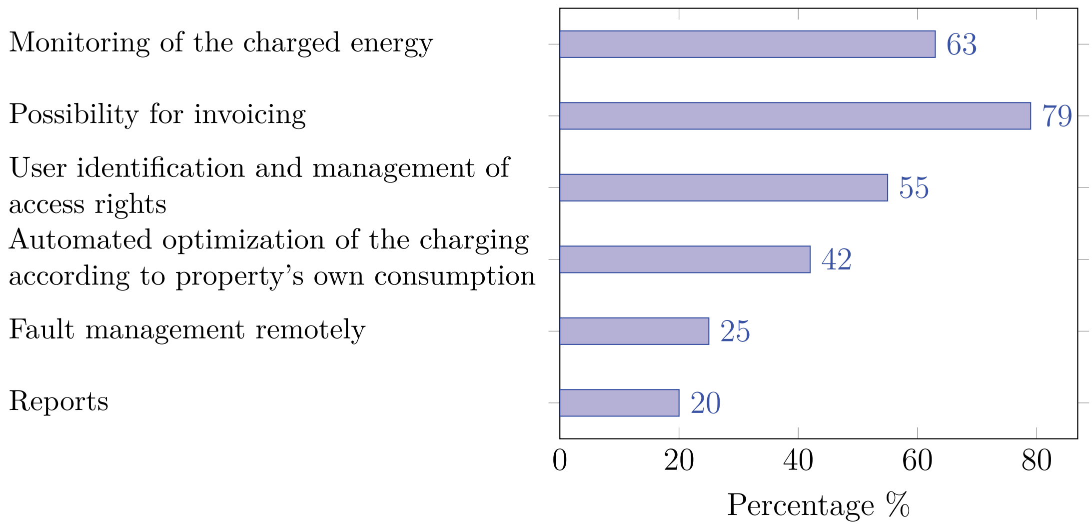
10. Who would mainly use the charging points in the properties that you manage?



11. Which one of the two chargers would be more beneficial to your property?



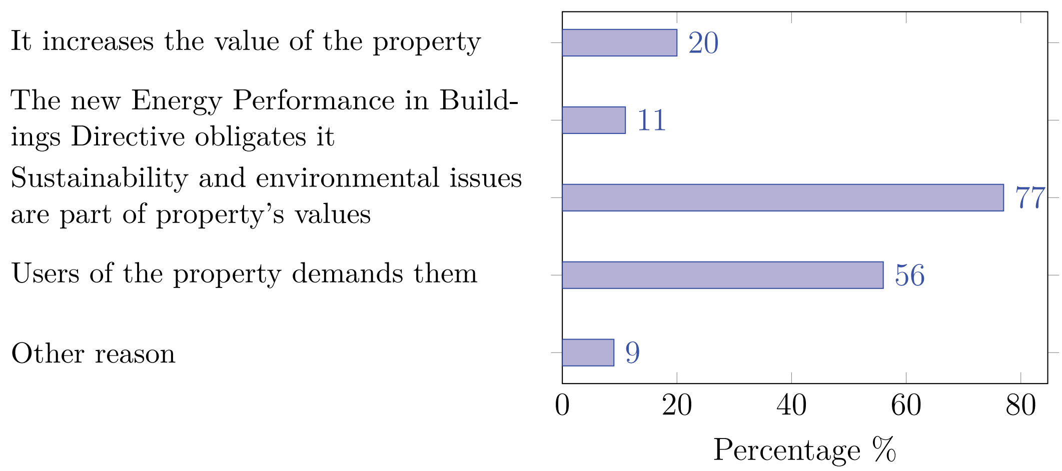
12. Which of the smart chargers features would you consider being the most important for your property? Choose the 3 most important features.



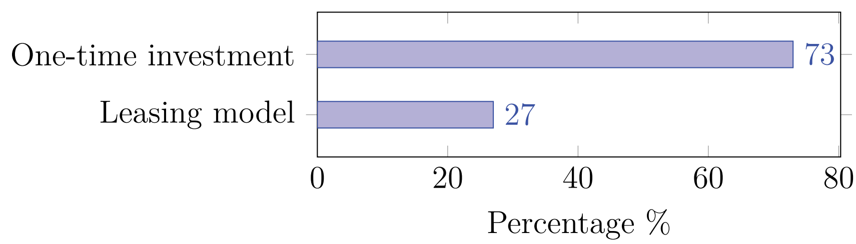
13. Who should be responsible for the features regarding charging points listed below?

	Facility Manager (%)	Contractor (%)	Service provider (%)
Installation and commissioning	8,2	43,6	48,2
Management of access rights	51,8	0,9	47,3
Invoicing	37,6	0	62,4
Service and maintenance	5,5	11,8	82,7
Customer support	6,4	2,7	90,9

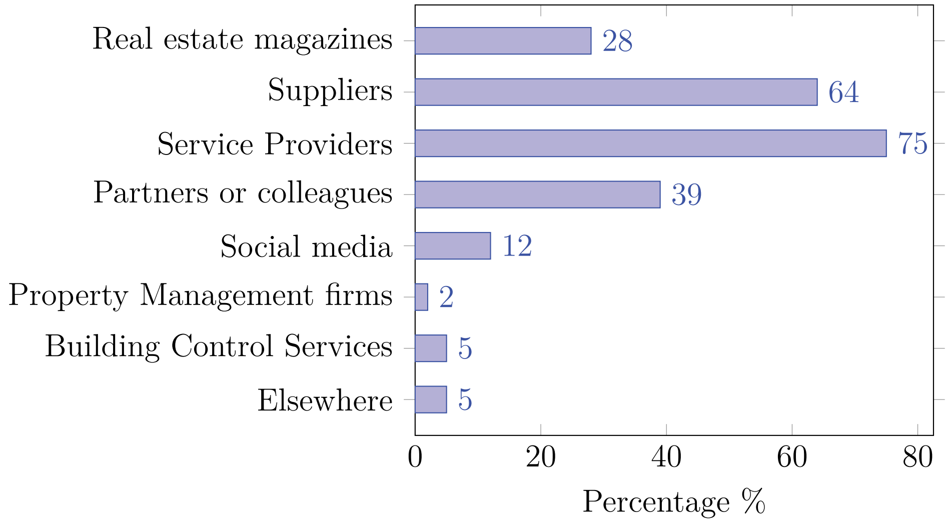
14. Why do you think that EV charging points should be installed to properties?



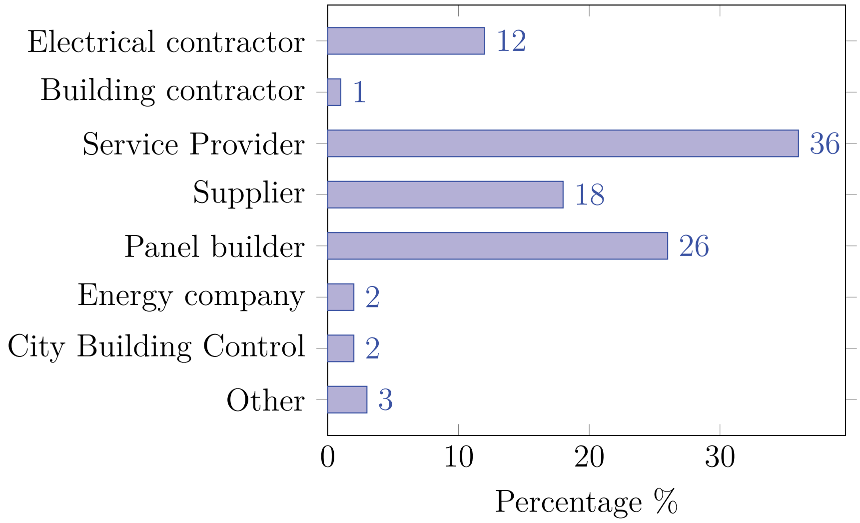
15. Which form of financing are more interesting when purchasing EV charging points?



16. Where do you find information regarding EV charging points?



17. Who would you contact first when purchasing EV charging points?



18. What thoughts do the increasing number of EVs evoke?